265

LIFE CYCLE ASSESSMENT (LCA) FO OVERHEAD LINES

Working Group B2.15

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Life Cycle Assessment (LCA) for Overhead Lines

Life Cycle Assessment and Environmental Concerns

CIGRE Working Group B2-15

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Table of Contents

Page

1. INTRODUCTION

Working Group B2.15 was set up in 2000 to examine Life Cycle Assessment (LCA) issues as applied to Overhead Lines and to study aspects relating to overhead line relating to Environmental Concerns. With regard to LCA the specific terms relating to reference were:

1. To analyse LCA methods and existing tools and to ascertain their range of application for overhead lines.

2. To develop methodologies as appropriate for Life Cycle Assessment of Overhead Lines, establishing recommendations to provide as complete a picture as possible of the interactions of an overhead line with the environment and to provide decision makers with information which identifies opportunities for environmental improvement.

For clarity it is useful to give here the definition of LCA from the Society for Environmental Toxicology and Chemistry (SETAC):

"The Life Cycle Assessment is an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying, and quantifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials, manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal.

The Life Cycle Assessment addresses environmental impacts of the system under study in the areas of ecological health, human health and resource depletion. It does not address economic considerations or social effects. Additionally, like all other specific models, LCA is a simplification of the physical system and cannot claim to provide an absolute and complete representation of every environmental interaction."

The working group has undertaken a broad examination of LCA and LCA methodologies. A summary is given of how LCA developed and how it is classified and outlined in the ISO 14040 series. A full review is included of work done in Scandinavian countries on LCA on power systems and overhead lines. A very detailed explanation and comparison is provided of various LCA software packages, how they operate and their benefits.

To develop working group documents on LCA the approach adopted was to examine the main components of overhead lines - structures and foundations, conductors and insulators – and to initially assess in a qualitative manner the impact of these components on the environment through the production, use and disposal phases. Furthermore a series of detailed quantitative LCA studies have been carried out on the main overhead line components (using Japanese LCA software). The results of some studies (in Japan and Denmark) dealing with the overhead line as a system are also included. Finally conclusions and recommendations are presented.

LCA is one of the tools for the evaluation of the environmental impacts of products or systems. It should be noted that the objectives of LCA are evaluation of the global burdens and that the method intrinsically excludes the local impacts.

(Electric and magnetic fields (EMF), audible noise and other interference issues connected to transmission lines are not covered by this technical brochure, since they have already been dealt with in detail in Technical Brochure 147, *High Voltage Overhead Lines – Environmental Concerns, Procedures, Impacts and Mitigations,* from SC 22.14, as well as by other working groups in CIGRE and they, like visual impact, cannot be analysed using LCA methodologies).

Some of the studies reported on were driven by demands of customers in deregulated markets for more information on the environmental effects of overhead lines. This brochure should certainly assist in that regard. It is hoped that the information contained in this technical brochure will be of benefit to CIGRE members and those working in electrical power systems in providing an overview of Life Cycle Assessment, its application to overhead lines and the possibilities for environmental improvement. It could also serve as a model of the application of life cycle assessment to other components of an electric power system.

2. LCA DEVELOPMENT AND OUTLINE OF ISO 14040 SERIES

2.1 LCA Development and early applications

2.1.1 Introduction and historic overview to LCA

Triple bottom line accounting looking at **economical, environmental and social** costs and benefits is today considered to be the main overarching consideration in most industrial processes.

The realisation during the early 1960's of the finite character of the non-renewable resources of the Earth and effects such as global warming, accelerated by pollution resulting from industrial processes, highlighted the responsibility of managing industrial processes. This is evident from activities and research in early life cycle inventories which date back to this period .

Buchinger [1] cites the publication of Harold Smith at the World Energy Conference in 1963, as the first in its kind on cumulative energy requirements for the production of chemical intermediates.

This work was followed by the publications "The Limits to Growth" (Meadows et al. 1972) and "A Blueprint for Survival (Club of Rome) as cited by Vigon *et al*. (1994) [2].

Later the US Environmental Protection Agency (EPA) published their findings on material and energy inputs in various industries. Following the oil crisis of the mid 1970's, a number of persons and organisations in the US and Europe became active in this field [1].

The process of quantifying the resource use and releases to the Environment of products was first known as a Resource and Environmental Profile Analysis (REPA) in the United States and as Ecobalance in Europe [2].

Driven by the oil shortages Vigon [2] cites that approximately 15 REPA's were performed between 1970 and 1975. During this time assumptions and techniques underwent considerable review by the EPA and major industries and a protocol or standard research methodology evolved.

With the fading influence of the oil crisis, interest in comprehensive LCA waned during the period 1975 to the early 1980's with only a few studies concentrating mainly on life cycle inventories and emphasizing energy requirements .

During this time the interest of European LCA practitioners grew with the establishment of an Environmental Directorate by the European Commission. In addition to working towards standardising pollution regulations throughout Europe, this Directorate also issued the Liquid food container Directive in 1985. This charged member companies with monitoring the energy and raw material consumption and waste generation of liquid food containers .

During 1988, when solid waste became a worldwide issue, the life-cycle inventory analysis technique again emerged as a tool for analysing environmental problems. Both European and American consultants and research institutes further expanded and refined the methodology [2].

The Society of Environmental Toxicology and Chemistry (SETAC) served as the focal point for technical developments in LCA according to Vigon [2]. Several publications were produced during the 1990's, which may be obtained from http://www.setac.org. Some of the more important publications are "A Technical Framework for Life-Cycle Assessment, 1991" and "A Conceptual Framework for Life-Cycle Assessment, 1993". Several publications on LCA case studies are also available from this website.

2.1.2 Early applications of LCA in industry.

In response to the emerging environmental awareness of the 1960's, a number of companies investigated life cycle analysis. See Table 1 below.

In 1969 Coca-Cola laid the foundation for the current methods of life cycle inventory analysis in the United States. In this study researchers compared different beverage containers on the basis of quantifying releases to the environment and use of raw materials and energy from the manufacturing process [2].

A notable case of a retail chain using LCA was that of Migros in Switzerland. Migros operates one of the largest chains of grocery stores in that country. This company compared products from the raw materials input, through manufacturing, transport, packaging, use and disposal process. This was done by means of a computer-based environmental information system that was started in 1985. Later this system was expanded and in 1990 the system could assign negative "eco-points" to products based on environmental impacts associated with a packaging system, from resource extraction through to final disposal [3].

Schmidheiny [3] states that most of the LCA's done up to 1992 concentrated on the LCA inventory stage.

Client	Practitioner	Product	Year
Coca-Cola	MRI	Beverage containers	1969
EPA	MRI	Beverage containers	1974
SPI	MRI	Plastics	1974
Unknown	MRI	Beer containers	1974
Goodyear	Franklin	Soft drink containers	1978
Proctor & Gamble	Franklin	Laundry detergent packaging	1988
Proctor & Gamble	Franklin	Surfactants	1989
Unknown	Franklin	Soft drink delivery systems	1989
Council for Solid Waste Solutions	Franklin	Foamed polystyrene and beached paperboard	1990
American Paper Institute	Franklin	Cloth and disposable diapers	1990
Proctor & Gamble	A.D.Little	Cloth and disposable diapers	1990
Council for Solid Waste Solutions	Franklin	Grocery sacks	1990
Vinyl Institute	Chem systems	Vinyl packaging	1991
National Association of Diaper Services	Lehrberger & Jones	Diapers	1991
Council of State Governments	Tellus	Packaging	1991
Proctor & Gamble	Franklin	Hard surface cleaners	1992

Table 1: A list of LCA's conducted during the period 1969 to 1992 (source: Curran 1993 p.343 as cited by Buchinger [1].

2.1.3 The current application of LCA

LCA is one of many tools in environmental management. The relationship with other environmental management tools was investigated by SETAC- Europe working group in 1993 with the following aims to identify:

1) *ways in which these various approaches to environmental management can fit together to enhance the overall environmental decision-making process; and*

2) *areas of data commonality /interchangeability to avoid inter alia , unnecessary duplication in effort. "*

This report also states that LCA is increasingly recognised as a potentially powerful environmental management tool and is increasingly being used in environmental management systems of companies as well as by governments in the policy making process [4].

This relationship of LCA with other environmental management tools, the approach and ultimate goal of sustainable development was studied by the SETAC-Europe group and described by means of the following diagram. It shows a common data set for all the tools.

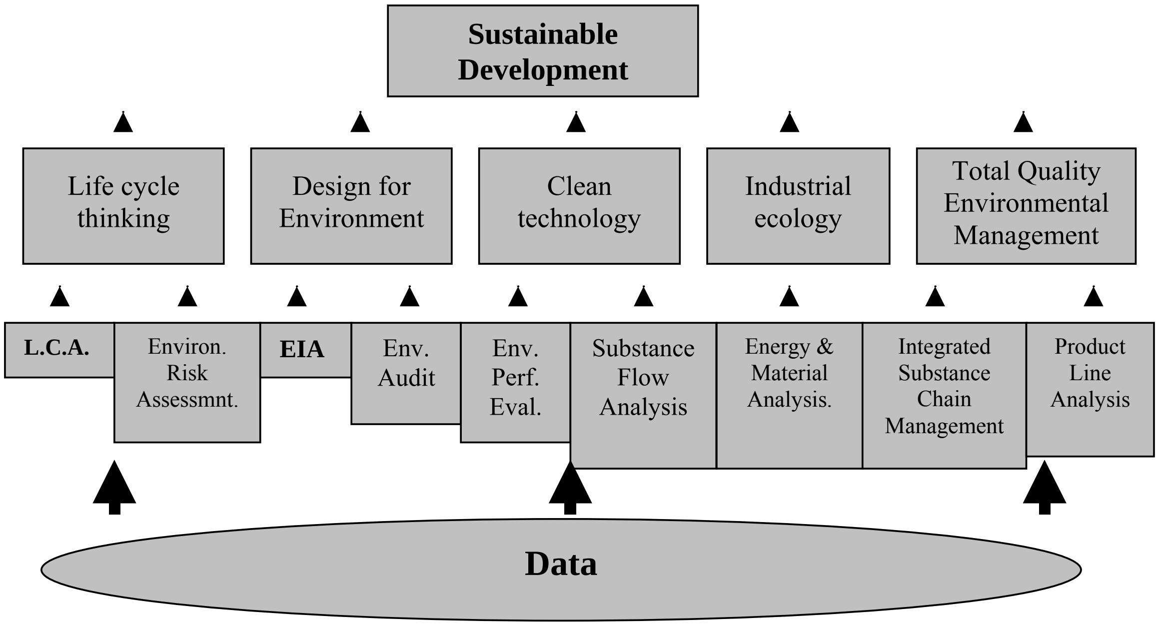

Figure 1: The relationship of ultimate goal, approaches and tools in environmental management with a common data set (After SETAC-Europe Working group)[4]

A number of groups are active in the application of LCA in a variety of fields. In addition to the Society of Environmental Toxicology and Chemistry (SETAC) other important ones are the Society for the Promotion of Lifecycle Development (SPOLD) and the United States Environmental Protection Agency (USEPA).

LCA is applied to a wide spectrum of fields. This covers industrial, commercial and agricultural arenas. Numerous examples may be found on the Internet. One example may be found at http:// www.epa.gov/ORD/NRMRL/lcaccess/r.htm

The LCA approach and methodology is also not static and is continually being developed. Due to the extensive effort required for LCA, the North American streamlined LCA Workgroup of SETAC investigated the definition and documentation of a shortened form of LCA. The group found that streamlining the LCA is an inherent part of any LCA and the key is to link the streamlining process closely to the goal and scope definition process [5].

Following the work by SETAC on LCA as outlined above, and spurred on by the heightened awareness of the importance of environmental protection, a series of international standards for the execution of LCA was developed and published by ISO in June 1997. These are discussed and the methodology outlined in Section 2.2 below.

2.1.4 The application of LCA in the electrical industry

References to LCA on electric power systems are noticeably scarce in the earlier literature. Following on from the Connecticut Public Act 94-176, entitled " An Act Concerning Life Cycle Cost Analysis and Certain Electrical Facilities", the Connecticut Siting Agency initiated an investigation into comparative life-cycle costs of 31 overhead and underground line configurations [6]. This was however not a true LCA, which requires the measurement of resource, energy usage and emissions and waste.

These types of studies came about later. During the mid 1990's in Sweden studies were undertaken which included not only the generation system but all the networks inclusive of transformer substations, overhead lines and cables. This focused like earlier studies in industry on the LCA inventory stage. This was followed by one in Denmark which was a full LCA study undertaken not only to evaluate the environmental impact from the Danish electricity sector but also to provide information for other companies work in LCA. These studies and their results are presented in detail in Chapter 3.

Some studies have been carried out involving overhead lines elsewhere (for example on different types of low voltage and medium voltage lines and comparative interconnection studies in Italy and on different methods of right of way maintenance in Canada) but the Scandinavian studies are the most comprehensive undertaken to date.

Electricity features prominently in many LCA studies and as no consistency exists in how this data should be calculated and presented a three day workshop was held in October 2001 to discuss life cycle inventory data for electrical production [7].

A few references on LCA presentations at seminars and conferences are available at http://www.epa.gov/ORD/NRMRL/lcaccess/r.htm. These cover topics on environmental labeling of green electricity and comparative studies on different types of power generation and fuels.

It been shown that LCA was one of the earlier environmental techniques developed to assess environmental impacts. It is a technique that is still in development. It is therefore logical that this technique should be applied to electrical systems including to overhead lines.

This report moves the position on LCA and overhead lines on further as it provides a comprehensive survey, inclusive of conclusions and recommendations, of what has been achieved to date based on the studies of others and those of the working group.

2.2 Outline of ISO 14040 series

2.2.1 General Structure of ISO 14040

The ***ISO 14040 Environmental Management - Life Cycle Assessment*** series [8], [9], [10], [11]. [12], [13] deal with the principles and framework for conducting and reporting LCA studies. A short glossary of definitions of terms relating to Principles and Framework is given in the Appendix to this report. LCA studies are one of many environmental techniques whose aim is to systematically address the environmental aspects and potential impacts throughout a product's life, from raw material acquisition, through production, use and final disposal. The economic and socioeconomic aspects of a product are outside the scope of an LCA study.

Life Cycle Assessment shall include definition of goal and scope of the study, inventory compilation of relevant inputs and outputs to a products system (inventory analysis), evaluation of the potential environmental impacts associated with those inputs and outputs (impact assessment), and interpretation of the results of the inventory analysis and impact assessment phases in relation to the goal of the study.

In the following sections each of the LCA phases, as defined in the ISO standards, are reviewed, highlighting the most relevant aspects when applied to overhead transmission lines.

2.2.2 Goal

As defined by ISO 14040, ***"The goal of an LCA shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience…."*** Among the possible direct applications are the following:

- Product development and improvement
- Environmental reporting
- Comparative studies between function-equivalent systems
- Strategic planning
- Public policy making
- Marketing and others

When deciding the intended application of carrying out an LCA study, it must be borne in mind that each application will require a different approach and the scope particularly will be goal-dependent.

2.2.3 Overhead Lines Applications

Any of the aforementioned goals are well suited for the particular case of an overhead transmission line. However, LCA as the basis for an environmental report is one application that some electricity utilities are starting to consider. Both Danish Eltra and Swedish Vattenfall, carried out LCAs[1] to assess the environmental performance of their electricity systems, from generation plants to consumers.

Another application of LCA is the comparison of power transmission lines, i.e., evaluating which of several existing or prospected power line solutions is the most environmentally friendly in transmitting electrical energy. In general, for the results to be comparable, the systems evaluated must have identical functions (e.g., transmission of energy between two locations). Further, the comparison must be made in terms of the so-called functional unit, that is, the adverse environmental effects of each system must be expressed per unit of useful function delivered by that system, while any differences that only affect the internal workings of each system must be ignored in the comparison (see section 2.2.4.2). The underlying principle is that what has to be compared is the environmental cost per unit benefit. In this way, for instance, two transmission lines capable to sustain different power levels between the same locations can be fairly compared by dividing their absolute environmental impact, however defined, by the respective power [or "by the energy they deliver"], while the voltages at which they operate can and should be disregarded.

[1] See Chapter 3.

LCA is considered a suitable tool for the optimization or the overall product improvement or improvement of overhead transmission lines. For example, by pinpointing which are the most relevant environmental burdens of the transmission line or transmission grid, actions could be taken in order to alleviate this effect. This also applies to the overhead line components to improve their environmental performance by determining the most environmentally important process over each of their life cycles. A transmission line itself is a mixture of many components, and this means that product improvement for each component eventually results in product improvement for a complete transmission line.

2.2.4 Scope of Study

The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal or application.

In defining the scope of an LCA study, the following items should be considered and clearly described:

- The function(s) of the product system and its functional unit
- The product system to be studied and its boundaries (system modeling)
- Allocation procedures
- Types of impact to be considered
- Data requirements, assumptions and limitations
- Type and format of the report required for the study
- Type of critical review, if any

Even though the aforementioned issues should be clearly defined before proceeding to the inventory phase of the study, the ISO standards acknowledge that LCA is an iterative technique; therefore, the scope of the study may need to be modified while the study is being undertaken as additional information is collected.

Whereas the goal definition probably falls into one of the categories mentioned in the previous section, the scope of an LCA is very much product-dependent, and all the issues addressed in this phase will be particular to the product system which is to be studied. In this way, some of the scope items are singled out for the particular case when the product system is the overhead transmission grid.

2.2.4.1 Product system and its boundaries

Before the function and functional unit are accurately defined, the product system and its boundaries must be properly defined and modeled. Three options are presented to illustrate this point:

a) The product system comprises the whole electricity chain from generation to consumer points. If this approach were to be considered, then the different unit processes would be energy generation, energy transmission up to the distribution substations, voltage transformation, and final distribution to consumers.

b) Because option can require enormous amounts of resources to complete, (and given that the scope of WG 15 was to define an LCA methodology for OHL), then it would seem reasonable that just the overhead transmission grid be studied. This system would be interlinked to others, for example, the generation system or the voltage transformation system by intermediate product flows, and to the environment by the so-called elementary flows[2]. The proposed model for the system is represented in

c) **Figure** 2. Here, the intermediate flow from the generation to the transmission system (white arrow 1) would be the kWh generated, whereas the intermediate flow from the transmission to the voltage conversion system would be the kWh generated minus the transmission losses (white arrow 2). On the other hand, all elementary flows directly associated with the transmission system under study are represented by blue arrows. At this point it is necessary, in order to accurately assess the environmental performance of the grid, that its transmission power losses are considered as well as the associated environmental burdens these losses represent in the power generation phase (orange arrows).

According to ISO 14041 "ideally the product system should be modeled in such a manner that inputs and outputs at its boundary are elementary flows." If this recommendation were to be followed, option (a) would be the one chosen for the system boundaries. However, ISO 14041 also points out: "In many cases there will not be sufficient time, data, or resources to conduct such a comprehensive study, so decisions shall be made regarding which unit processes shall be modeled by the study and the level of detail to which these unit processes shall be studied". This other comment would justify option (b).

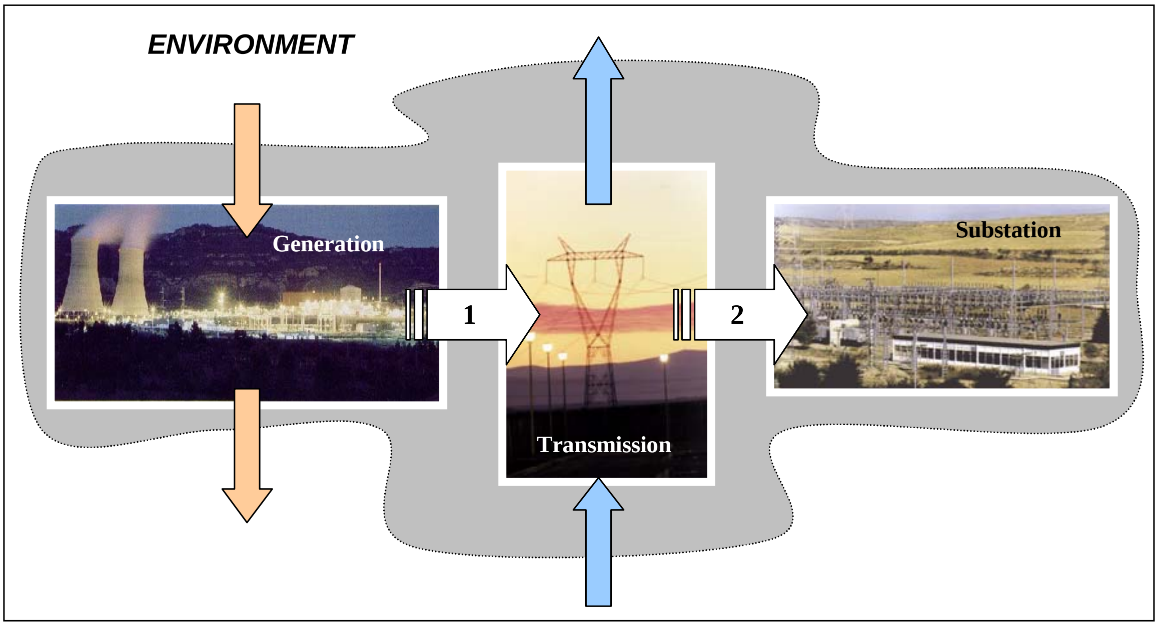

Figure 2: Model for overhead transmission grid

[2] Material or energy entering the system being studied, which has been drawn from the environment without previous human transformation. Also, material or energy leaving the system being studied, which is discarded into the environment without subsequent human transformation.

d) An overhead transmission grid itself is a rather large system, which consists of several sub-systems made up of various components, their transportation, erection work, maintenance activities, dismantling, transmission losses, and so on (see Figure 3 below). Considering that elementary flows for the transmission system are the sum total of elementary flows for each sub-system, it is necessary to regard these sub-systems (such as OHL components) as one of the product systems to be studied.

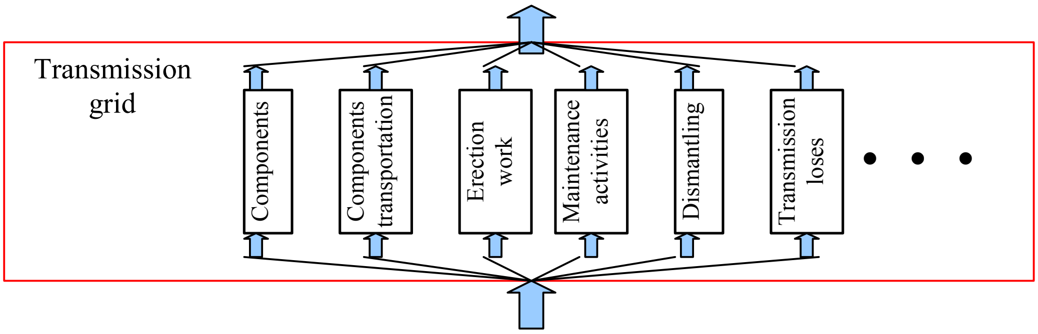

Figure 3: Model for sub-systems of an overhead transmission grid

One of the options (a), (b), or (c) can be adopted depending on the application of the study. In any case, when setting the system boundaries and dividing the process into unit and subunit processes, factors like the application of the study, the assumptions made, cut-off criteria, data and cost constraints, and the intended audience, must be considered. All this must be clearly identified and justified in the scope of the study.

2.2.4.2 Function and functional unit

The primary purpose of expressing the results of an LCA study in terms of functional units is to normalize each factor of environmental impact against the amount of useful functions provided by the product being evaluated. When defining the functional unit to adopt, it is necessary to consider all the main useful effects of a product or, in other words, all aspects of its "function" (hence, presumably, the term "functional unit"). This normalization is necessary to ensure the comparability of LCA results between different products.

If the system scrutinized is a transmission grid (option (b) in section 2.2.4.1), then its function is to supply electricity all the way to the transmission/distribution substations. With the intended goal of the study, system and function as they have been defined, the useful function of the system consists of two components that must both be considered: the amount of energy delivered to the substations and the distance over which such energy is transmitted.

For instance, it is clear that power lines operating at a higher voltage have in general a greater impact on the environment; but when the burdens are estimated per unit of energy transmitted, it is no longer necessarily true that a 400 kV grid has a heavier impact than a 132 kV grid.

The same could be said when comparing lines of different lengths. Even though longer lines of the same voltage level tend to represent more significant burdens to the environment, when the impact is estimated per unit of length, the various impacts are not necessarily greater for the longer lines.

All in all, when comparing power lines or grids having different voltage levels or lengths, the environmental burdens should be expressed per kWh and per km, that is, as ($^{1}/_{kWh.km}$).

If the purpose of an LCA study is product or process refinement for a same case of application, with assigned voltage and corridor path, then the burdens can be estimated in absolute terms. Even in that case though, using functional units would turn the results into knowledge reusable for possible future comparisons with different transmission systems, technology evaluation studies, etc.

When the purpose of an LCA study is OHL component production refinement, the functional unit might be, for example, one disc insulator or a number of discs or a metre of conductor. However if the result of the study is also used as a part of the transmission grid LCA data, it is necessary to establish the functional unit conversion method (from such as [burden/disc] to [burden/kwh*km]). Because as explained earlier, the functional unit is the amount of useful performance of a system that is used as a reference for expressing material and energy flows, and that consequently in the case of power transmission systems it is measured in [*kWh*km*]. This conversion could be derived from the relationship between transmission grid and components e.g. how many disc insulators are used for 1 km of 132kV grid?

2.2.4.3 Allocation procedures

No matter which system is to be analysed and how it is modeled, the allocation criteria should always be similar. Unit processes and sub processes as generation and transmission are typical activities where allocation procedure will be needed.

Whereas in some activities like transportation, this allocation/distribution of impacts will be done based on the mass or volume of the products being transported, in other processes like power generation in combined cycle plants, the allocation would be done based on the energy output (either electric, thermal, etc.)

2.2.4.4 Types of impact to be considered

In addition to the types of impacts included in Eltra's LCA study on the whole electricity chain from generation to consumer points, that is, greenhouse effect, acidification, ozone formation, nutritive salts impact, human toxicity, ecological toxicity, persistent toxicity, voluminous wastes, hazardous wastes, radioactive wastes, slag and ashes, other impact categories like resource depletion and land erosion should be considered.

However visual impact, EMF, and noise cannot be included as impact categories, as LCA studies, by definition, cannot address these effects.

2.2.4.5 Data quality requirements, assumptions and limitations

No matter which product system is chosen, if the results of the LCA study are to be taken seriously, the representativeness of the population studied is one of the major requirements, Representativeness, according to ISO 14041 is "the qualitative assessment of degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage). For example, if an LCA is to be undertaken to assess the environmental performance of the transmission grid in one country, and because the study of every single transmission line would be materially impossible, then certain lines would have to be chosen as representatives of the whole grid. Further data quality requirements which should be defined in accordance with the intended goal, prior to the inventory phase, are the nature of the data (collected in situ or extracted from published sources), whether the data should be measured, calculated or estimated, and the precision and completeness of the different data categories.

As for the assumptions made in the modeling of each product system, and based on the intended application, some unit processes may be left out of the study and some simplifications made. Both data quality and assumptions/simplifications made in the modeling of the system will set limitations to the overall result of the LCA study.

2.2.4.6 Study report and critical review considerations

The results of an LCA study should be fairly, completely and accurately reported to the intended audience with the format proposed and described in section 8 of ISO 14041.

Critical review is a technique to verify whether an LCA study has met the requirements of the ISO standards for the methodology, data and reporting. In general, critical reviews of an LCA are optional, but as presented in ISO 14040, shall be undertaken, when the results of comparative assertions are to be disclosed to the public.

2.2.5 Life Cycle Inventory Analysis

Whereas the definition of the goal and scope provides the initial plan for conducting an LCA study, the Life Cycle Inventory (LCI) analysis is concerned with the data collection and calculation procedures in order to quantify relevant inputs and outputs of a product system.

Such data may be collected from the production sites associated with the unit processes within the system boundaries, or they may be obtained or calculated from published sources. In practice, all data categories may include a mixture of measured, calculated or estimated data.

The process of conducting an inventory analysis is 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 data collection procedures so that the goals of the study will still be met.

The operational steps to be followed as defined by ISO 14041 are represented in the flowchart of Figure 3. Of the aforementioned steps the data collection can be the most resource intensive process. Practical constraints on data collection should therefore be considered in the scope.

LCI analysis has a well-defined structure which is common to any product system under study. Once the goal and scope have been properly defined, the carrying out of the inventory phase is straightforward if the steps in Figure 4 are followed according to the descriptions included in ISO 14041 (although it might be very time consuming)

Each product system (a), (b), or (c) (see section 2.2.4.1) will require inventory of data category from several unit processes. It seems reasonable that these data sets are obtained from the appropriate sources. In this way, the gas emission associated with the generation of one kWh can readily be supplied by the personnel of the generation plant considered, the fuel employed in the transportation of fuel, construction material, etc, could be inventoried by the transport company, and so on.

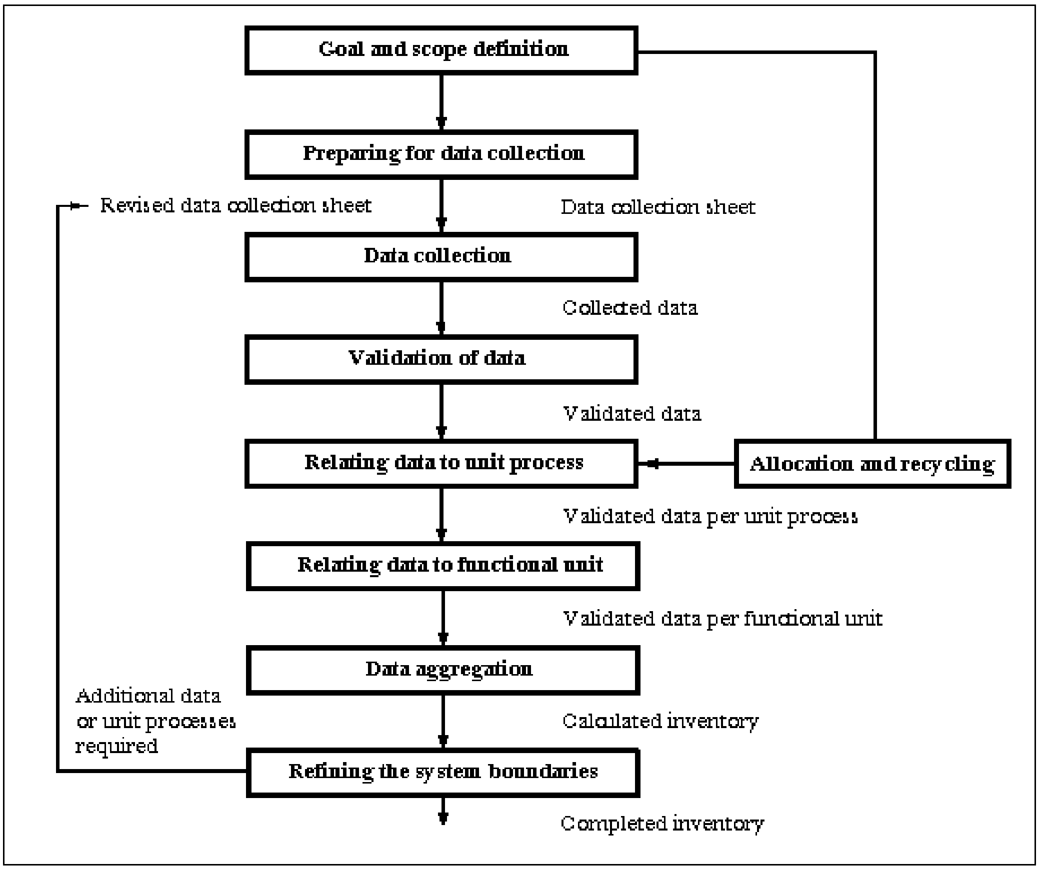

Figure 4: Life Cycle Inventory Analysis

Whereas the data collection is probably the most resource intensive process, the design of the data collection sheet is, at least at the preliminary stage of an LCA study, of great importance in the way it defines what data is required for the considered activities over the different phases of time.

The unit process of power transmission must be studied over different areas like manufacturing, construction, operation, maintenance and dismantling. Furthermore, for each of the aforementioned phases there could be other associated sub processes such as natural resource extraction or transportation, to name a few.

It is worthwhile commenting on the need for inclusion of the generation operation phase in the data collection sheet. The reason for this is the power transmission losses and the impact they represent in the generation operation phase in terms of additional emissions and burdens to the environment.

In Chapter 7, which presents LCA studies on overhead line components, detailed inventories for the various components can be found.

2.2.6 Life Cycle Impact Assessment

Life cycle impact assessment examines a system's LCI results to better identify their possible environmental relevance and significance, making these more understandable and manageable in relationship to the natural environment, human health and resources.

According to ISO 14042 the general framework for a Life Cycle Impact Assessment (LCIA) is made up of the following four stages:

- Selection and definition of impact categories.
- Classification, i.e. assignment of the appropriate inventory results to the selected impact categories.
- Characterisation, i.e. modeling of the inventory results for each category in terms of a category indicator, thus giving rise to the category indicator results.
- Valuation, i.e. the aggregation of several category indices into one category indicator, by defining weigthing factors across the same environmental impact categories.

The choice of the impact categories to be considered should be justified in relation to the goal and should be initially included in the scope of the LCA study.

The classification element aims to assign inventory results to impact categories. In some cases this is not a direct operation as some inventory results may relate to several impact categories.

The aim of the category characterisation or modeling is to provide a basis for the aggregation of inventory results within a category. This is done in terms of an indicator. This characterisation sub-phase of an LCA study is probably one of the most difficult, because the definition of some category indicators might turn out to be a very subjective task. One example of an impact indicator is global warming. A characterisation factor, the global warming potential factor for each greenhouse gas, is used to calculate the global warming potential indicator in units of carbon dioxide equivalent. Other impact categories and their corresponding characterisation factors are illustrated in annex D of ISO 14042.

Because of the subjectivity associated with the different category indicator definitions, the use of a global indicator known as a milliperson equivalent (mPE) can prove to be more advantageous than the different indicators for each category.[3] The reason is twofold: for one thing, the use of a global indicator allows the aggregation of impacts corresponding to different categories (valuation sub-phase). The second reason has to do with the simplicity of expressing impacts in terms of mPE; once the input/outputs of the system have been inventoried, the computation of the mPE is straightforward from the definition of mPE. mPE is used in the Danish studies described in Chapter 3. Obviously, the global input/outputs of the impact categories considered have to be known, but especially for the most common categories, like the greenhouse effect, acidification, human health and others, there are numerous data inventories accessible via the Internet that report on total emissions to the atmosphere.

In any case, there are certain impact categories like land erosion, and impacts on fauna and flora whose characterisation is much more subtle in terms of the global indicator. The fundamental reason is the fact that these impact categories are usually defined in a rather qualitative manner, instead of quantitatively.

2.2.7 Interpretation of an LCA Study

There is no standardised methodology for the interpretation phase of an LCA because there are so many viable options, and therefore no unique approach is feasible. However, this last phase of an LCA study should comprise the following three steps:

- Identification of the significant environmental issues based on the results of the LCI and LCIA.
- Evaluation which shall a) verify that information from the different phases (LCI and LCIA) is sufficient for interpretation b) estimate the effects on the outcome of the study of the chosen methods and data and c) verify that the interpretation is done in accordance with the goal and scope definition.
- Conclusions, recommendations and reporting on the significant environmental issues.

For example, if an LCA has been carried out, with its application being the improvement or refinement of the power transmission through an overhead line (from an environmental point of view), and it shows that the emission of toxic gases in the generation process is the most relevant effect upon the environment, then the power transmission losses become a crucial factor. At this point the decision could be made within the electric utility to study upgrading the transmission grid to a higher voltage level. In the case of overhead line components if recycling of some components is shown to have a major benefit then studies could be undertaken to improve this aspect.

[3] $$1\ mPE = \frac{Country\ annual\ emission\ or\ Country\ annual\ consumption}{Country\ population\ x\ 1000}$$

3. POWER SYSTEM AND OVERHEAD LINE LCA IN SCANDINAVIA

Only a few power and transmission system LCAs have been done in the world. Vattenfall performed the first one in Sweden in the mid-1990s. Danish power companies have completed a similar, more recent study. While it is known that some LCA studies involving overhead lines have been performed elsewhere the Scandinavian studies are the most comprehensive, with available reports combined with accessible sources and these are therefore summarised here.

3.1 Sweden

Vattenfall AB generates about 20 per cent of the electricity in the Nordic region and also operates in Germany and Poland. As a result of the deregulation of the electricity market, many customers want more detailed information on electricity production and distribution, as well as the associated environmental impact. Vattenfall carried out a comprehensive LCA of its system of electricity generation in the mid-1990's, in order to obtain information and be transparent in its communication.

In Sweden, electricity is primarily generated by hydro and nuclear power plants, with additional capacity provided by other energy sources. Besides hydro and nuclear power, Vattenfall also assessed its oil-condensing plants, gas turbines, biofuelled combined heat and power (CHP) plants, wind-power plants and combined-cycle natural-gas plants. The review, which was completed in 1996, was summarised in a report issued the same year [14].

Simultaneous to the LCA work on the electricity generation system, a corresponding review of transmission and distribution systems began early in 1995. The studies concerned were carried out by Vattenfall in co-operation with Svenska Kraftnät and Göteborg Energi Nät AB. Svenska Kraftnät is responsible for administering and operating the national grid (220 and 400 kV). The regional networks (130 and 70 kV) are owned by various companies, including Vattenfall. Göteborg Energi Nät, for example, owns the regional network in Gothenburg (Göteborg), Sweden’s second-largest city. Local distribution takes place via local networks (0.4–40 kV). Today, there are slightly more than 180 companies distributing electricity in Sweden and about 130 commercial businesses that sell electricity.

3.1.1 Methods

The methods and procedures used in the LCA studies on transmission and distribution systems were those proposed in guidelines from SETAC (the Society of Environmental Toxicology and Chemistry) [15]. These guidelines have subsequently been developed and adapted to Nordic conditions [16].

The study included description and quantification of resource consumption and factors with a crucial bearing on the environmental impact. This included the complete chain, from production facilities via transformer stations, overhead lines and cables, to the customer. A summary and analysis of resource consumption and potential environmental impact was carried out for each section of the grid. A composite picture was then presented. The study was not a complete life-cycle assessment, since it was comprised of only the first two phases namely Inventory Analysis and Environmental Impact Classification, and is thus better described as a life-cycle inventory (LCI). The last two phases in a complete LCA are Characterisation and Valuation.

In order to obtain support and, at the same time, ensure quality of this work, co-operation was established with the Swedish Environmental Research Institute (IVL), which is an active participant in LCA projects.

3.1.2 Functional unit

The transmission of 1 kWh of electricity was selected as the functional unit in the study. This unit was chosen because it describes the utility of the system. It also permits the analyses to be combined with the LCAs carried out for electricity generation and the estimation of the total environmental load per kWh of electricity delivered to the customer. The results can then be used in other LCAs.

The study consists of an extensive inventory of existing grids. Since the system is highly complex, the study is modular, i.e. the loads per pylon site, kilometre of line, kilometre of cable, substation, etc are studied separately. Electricity transmission, emissions, energy and material consumption per kWh transmitted were calculated via the modules. Transmission losses were included in these calculations.

3.1.3 Systems and system limitations

An LCA is intended to study all environmental impacts “from the cradle to the grave”. This is, not, however, feasible in practice as one can continue indefinitely in certain chains. Limits have therefore had to be imposed, based on qualitative and quantitative assessments of the factors with the most significant impact on the environment in the system studied.

The life cycle of the electricity transmission/distribution system studied comprised:

- Construction of transformer stations/switchyards and line grids.
- Production and transport of materials used in the construction and operation of transformer stations/switchyards and line grids.
- Transmission and transformation losses in the operation of grids and transformer stations.
- Operation and maintenance in the form of right of way (servitude) clearing, inspection trips, etc.
- Production and transport of chemicals used in operation and construction.
- Demolition of transformer stations/switchyards and line grids, including handling, recycling and deposition of demolition waste, but excluding excavation of foundations and underground cables.

As far as time limitations are concerned, the analysis related mainly to the time corresponding to the life of a single module. The limits chosen were 30 years for transformer stations/switchyards and 40 years for line grids. Geographically, the study was confined to facilities located in Sweden.

3.1.4 Inventory

Performing an inventory consists of surveying all flows into and out of the system. The inventory in this LCA was carried out systematically for each subsystem and every component process. The inflows comprised for example, materials and energy, and the outflows of emissions to air and water, and waste products.

Substantial amounts of both the total time and financial resources spent, were allocated to collecting quality data and also in processing and structuring this data for further analysis. Reporting results from a life-cycle analysis is always a matter of balancing completeness and clarity. Some data were excluded, where they were either lacking (such as production data for certain materials) or deemed to be of limited significance.

There is considerable difficulty in assigning values to various types of environmental impact. This has been a main reason why the Swedish study did not deal with the phases of characterisation and valuation in a complete LCA.

In the LCA context, allocation (distributing resources, for example) is carried out in order to apportion contribution for emissions and resource consumption in the process and transport operations within a life cycle.

As both new and recycled materials are used for construction of line grids, the question arises of how environmental impacts and energy needs resulting from the recovery, recycling and waste management activities, should be distributed or allocated between the various life cycles. Certain metals, such as copper and aluminium, can be recycled over and over again, and their environmental impact may therefore need to be apportioned among several life cycles. There are established principles for this allocation. In the Swedish study, the choice was made to follow the “50/50 method” described in the *Nordic Guidelines* [16]. The 50/50-method allocates the environmental loadings equally between the primary process and the waste utilisation process in simple cases where two life-cycles are involved. The principle may also be applied on cascade coupled systems consisting of more than two life-cycles.

3.1.5 Eight examples

Svenska Kraftnät, Vattenfall and Göteborg Energi Nät own different types of grids and have varying categories of customers. To cover these and make it easier to illustrate how the results affect an individual customer, eight examples were included in the assessment:

- 400/220 kV (national grid)
- 130 kV, urban and rural areas respectively
- 10 kV, urban and rural areas respectively
- 0.4 kV (households), urban and rural areas respectively
- tramway customer

3.1.6 Results

There are major differences in resource consumption and environmental impact between the various customer categories. For example transmission losses to a national grid customer amount to 2 per cent while for household customers they are 9 per cent, see Figure 5.

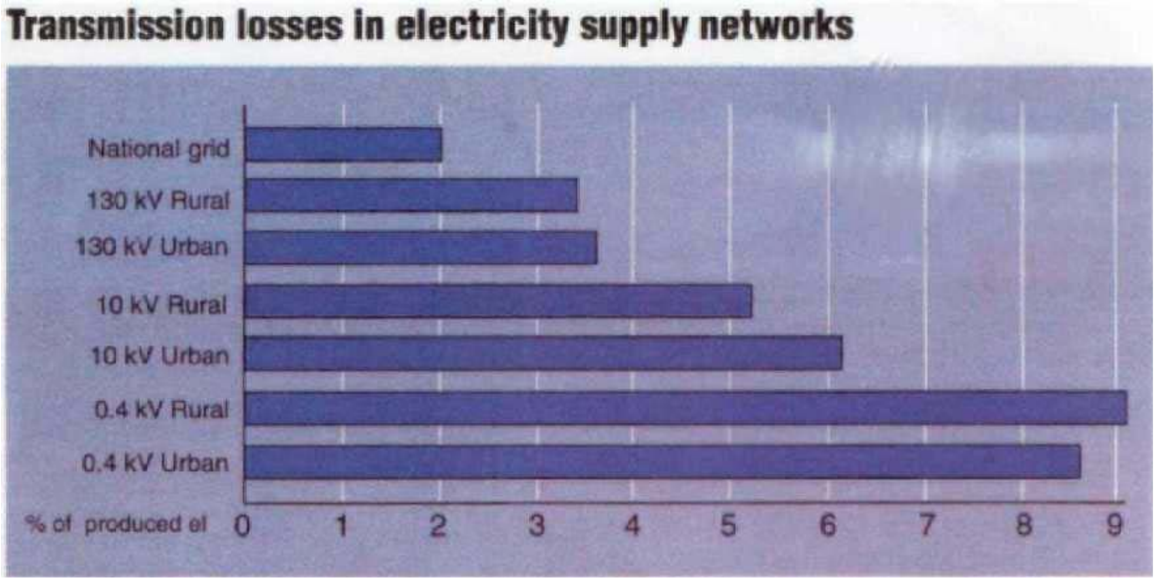

Figure 5: Transmission losses in electricity supply networks.

Emission of greenhouse gases, and also NO_x and SO_x, rise sharply with decreasing voltage levels. See the example in ***Figure 6***, relating to CO_2 emissions from distribution of electricity to various types of customer. Gas emissions are, however, marginal in a national perspective. Heavy metals are a greater problem than acidification and greenhouse gases. The results have been summarised in a leaflet, written for laymen, about Vattenfall's LCAs [17].

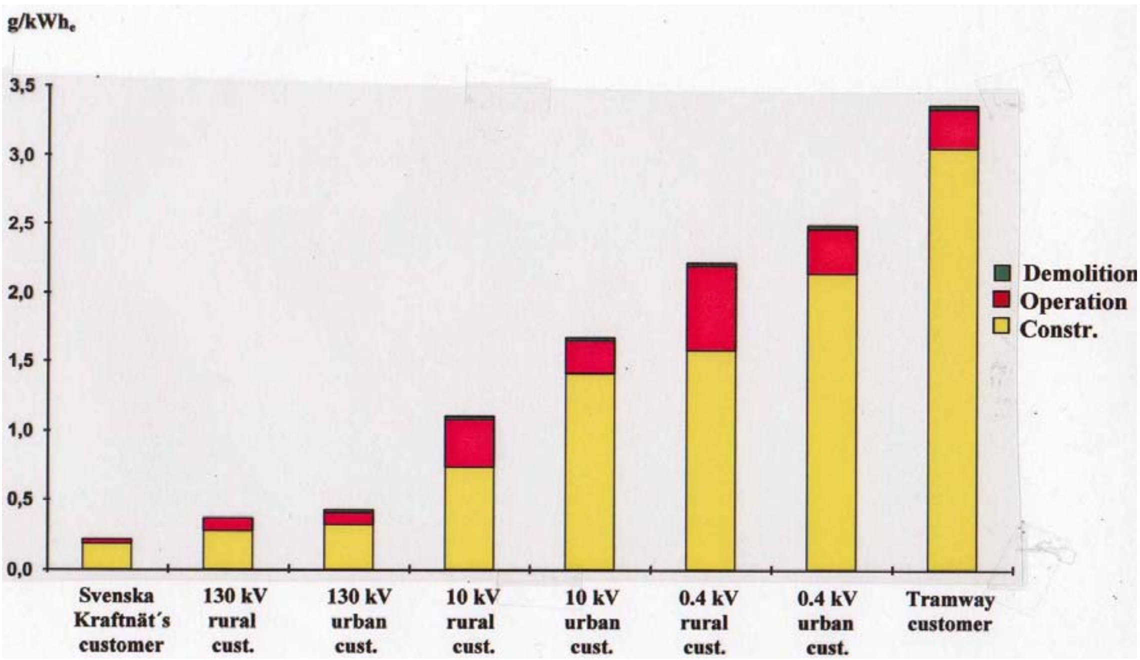

Figure 6: CO2 emissions from distribution of electricity to various types of customer.

The Swedish LCA-project was a great effort. There are no summarised figures available on manpower and costs, but the LCAs have involved numerous people in the participating companies, and enhanced their knowledge and awareness of environmental issues.

3.2 Denmark

Eltra is the transmission system operator in the western part of Denmark. and owns the 400 kV networks in Jutland and Funen, as well as the international connections with Sweden, Norway and Germany.

Eltra has been participating in a project to assess the life cycles of Danish electricity and CHP (Combined Heat and Power), including their environmental impact from coalmine to outlet. Eltra has been looking into the transmission system and the exchange of electricity with the neighbouring countries. The other partners in the project, Elsam, Elfor, Elkraft System and EnergiE2, have concerned themselves with generation facilities and the distribution network.

The Danish LCA review has superseded a simpler model from 1992, which omitted a number of factors, such as the network. This new LCA project relates to 1997 conditions.

The objective was partly a mapping and evaluation of the Danish electricity sector's impact and partly to make an important contribution to other companies' work in LCA. The study was subsequently updated with figures from 2000.

3.2.1 Methodology

The Danish environmental authorities have developed the general methodology applied in the Danish LCA review. It is more detailed, and addresses a larger number of issues than the international standards applicable. Further information about the methodology may be found on the Danish Environmental Protection Agency's website, *www.mst.dk*.

One of the major contributors highlighted during the LCA of overhead lines in Denmark, was waste connected to the decommissioning of lines. The Danish project is reported in the form of environmental impact profiles, in which a number of environmental effects, from the greenhouse effect to slag and ash, are expressed in person equivalents. This is defined below.

The methodology offers, for example, a conversion factor that enables figures on environmental impact to be compiled in a relatively limited number of categories, ranging from global greenhouse effect to local waste dumps. The LCA project has undergone internal and external quality control as well as a critical review to confirm that the methodology applied is appropriate.

3.2.2 System results

By far the most significant impact from electricity and CHP is due to the generation process. In this context, the contributions from transmission and distribution are relatively modest.

To assess whether environmental impact is reasonable compared with that of other activities in society, the impacting factors are expressed as person-equivalent (PE), i.e. the annual environmental impact of an average Danish individual, see Figure 7.

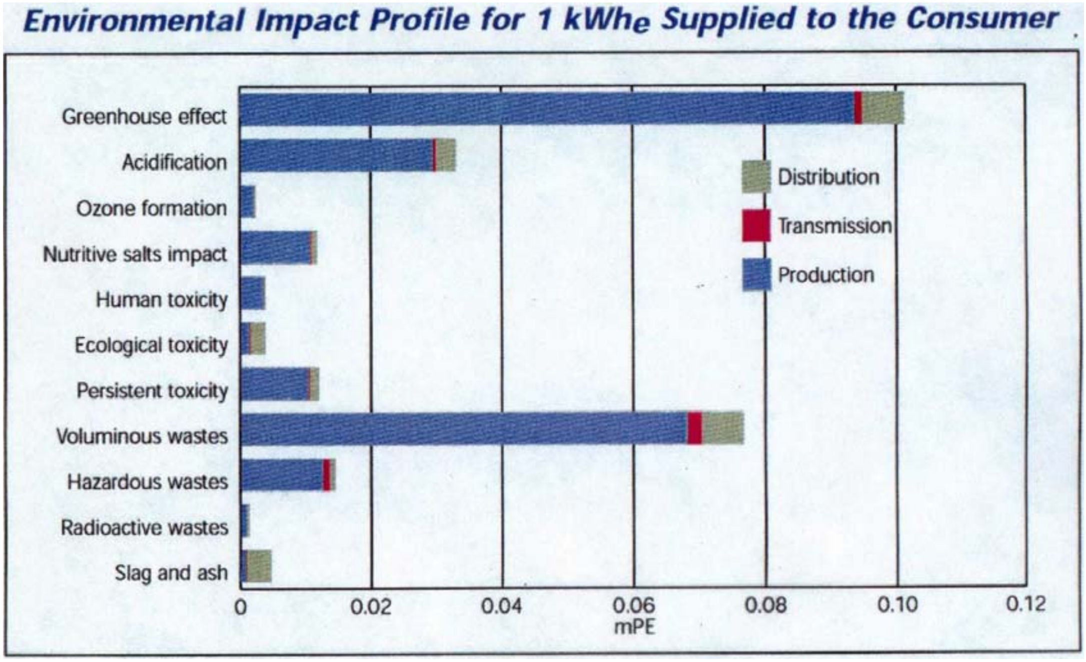

Figure 7: Sample environmental impact profile of supplying a customer with 1 kWhe in 1997 (mPE stands for milli person equivalent).

3.2.3 Transmission system

LCA models have been set up for the most important types of transmission-system components, such as overhead lines, transformers, etc. The models address production of materials, transport, civil works, supervision and maintenance, as well as dismantling, scrapping and re-use after decommissioning. Besides noise, magnetic fields and visual appearance, the impact is evaluated for four areas: plant establishment, operation, network losses and decommissioning.

Network losses are a major source of environmental impact from the transmission system.

Figure 8 shows an environmental impact profile for the transmission system. According to calculations, the average annual impact is less than 0.001 mPE per kWh consumed. Converting these figures to a Danish average personal consumption (6,000 kWh), the environmental impact resulting from the transmission system is less than 1 per cent of Danish average personal environmental impact. Large volumes of waste constitute the most significant environmental impact resulting from the transmission of electricity. This may appear surprising. However, the high impact results from the fact that most of the foundation is not recycled as well as from the procurement of the fuel used in the generation of electricity, to cover the network losses.

The continuing conversion from coal to gas and renewable energy results in a stable downward trend. The high volume of waste also includes items from decommissioned transmission systems, such as remaining concrete foundations, only a small part of which can be crushed and re-utilised for road construction.

The second-largest environmental factor is the contribution to the greenhouse effect, which results mainly from network losses. This figure is also positively affected by the increasing use of renewable energy.

Also the Danish LCA was a big project. 15 man-months were used for the transmission part. The total LCA from production to the customer's meter used 10 man-years and resulted in 10-12 reports. LCA was selected as the overall theme of Eltra's Environmental Report in 1999 [18]. This English language brochure summarising the project is available on Eltra's home page at http://www.eltra.dk/media/showMedium.asp?12183_LCID1033(note, underscore LCDID1033).

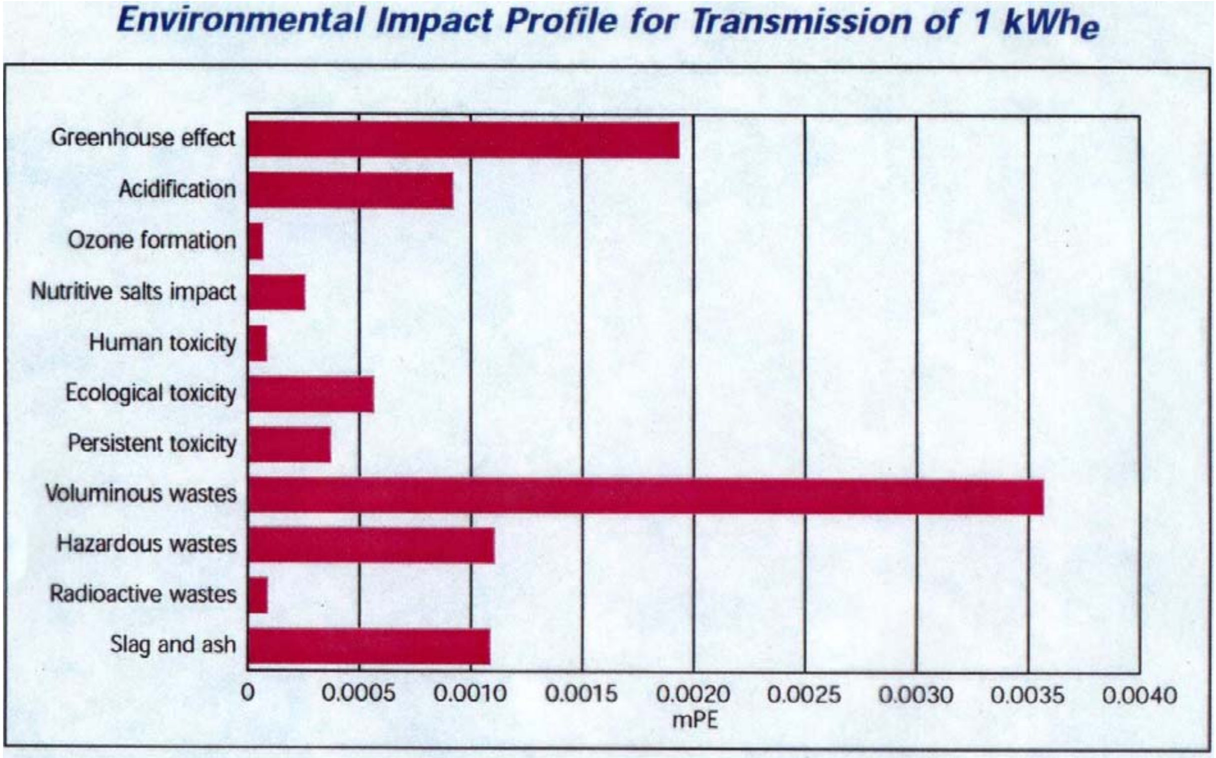

Figure 8: Example from the LCA programme: Environmental impact profile of the transmission of 1 kWhe.

3.3 Summary and conclusions

Two big LCA studies on power and transmission systems have been completed in Scandinavia – one in Sweden and one in Denmark. The methods are largely the same, and the results are expressed in the same functional unit, i.e. environmental impact per 1 kWh of electricity delivered to the consumer. The Swedish study is a life-cycle inventory, not a complete LCA, and for reporting purposes it is divided into eight different typical customers. The Danish project is reported in the form of environmental-impact profiles in which a number of environmental effects, from the greenhouse effect to slag and ash, are expressed in person equivalents.

The results show several similarities between countries regarding, for example, resource consumption for the lines themselves and transmission losses. There are also substantial differences. The latter are connected with the particular generation system in the country concerned and, accordingly, the environmental effect associated with generation of the electricity that is required to cover losses. Principally, electricity generation is based on hydro and nuclear power in Sweden and coal-fired power plants in Denmark. This results in very different choices with respect to technology, action area, research etc.

4. COMPARISON OF LCA SOFTWARE

4.1 Introduction

This chapter describes the basic functions of some LCA software packages (JEMAI, TEAM, Simapro), in other words what LCA software can do in general, and it also compares some of their features (see **Table 4,** at the end of this section)). JEMAI, TEAM, and Simapro are all LCA software packages which have similar functions, however because of their different origins (development institutions in Japan, France, and the Netherlands) there are some differences among them. This chapter describes the outline of the LCA software packages. However SCB2 WG15 did examine some of the detailed functions of JEMAI, and TEAM in WG papers.

4.2 Functions of LCA software

As specified in the ISO14040 series, Inventory Analysis and Impact Assessment are the major elements in LCA software. To carry out Inventory Analysis {compilation and quantification of inputs and outputs for a given product system (collection of unit processes) throughout its life cycle} easily, databases of unit processes is an important element of LCA software too.

4.2.1 Database of unit processes

Collection of all data required for one LCA study from beginning to end needs an enormous amount of work. Unit process data like material production, such as steel or glass production is commonly used for each LCA study, therefore it is effective to compile this data and store it in the software in advance. This data, which is not collected by individuals conducting LCA studies is often called “background data”, while on the other hand data, which is collected by those performing the studies first-hand, is called “foreground data”. Categories of background data stored in LCA software are as follows.

4.2.1.1 Intermediate product manufacturing (such as Aluminum, Iron or etc.)

This category covers a wide range of data related to material. The form of data is different between LCA software databases, for instance some data covers all upstream process up to “Resource extraction” and others may cover only one unit process (such as Aluminum manufacturing from Bauxite). In the latter case, other upstream data is stored in the database separately. Therefore this category includes data for “Resource extraction”, “Material manufacturing”, and “Intermediate product manufacturing”. The main sources of the data in this category are APME, BUWAL, and ETH-ESU-Zurich. (For details see **Table 4.**)

4.2.1.2 Transportation

Transportation data per unit (such as ton-km) are stored in this category. Transportation data for automobile, ship, railroad, and airplane are included, however the range of the stored data is different in each software package. The main sources of the data in this category are ETH-ESU-Zurich, and others. (For details see **Table 4.**)

4.2.1.3 Energy

Data for electricity and fossil fuel combustion is stored in this category. Data in this category covers the range from fossil fuel mining to fuel combustion. The main sources of the data in this category are BUWAL, ETH-ESU-Zurich, and etc. (For details see **Table 2.**)

4.2.1.4 Waste

Data for landfill, incineration, and recycling is classified in this category. (For details see **Table 2.**)

Sometimes some necessary unit process data cannot be found in the database; in this case those performing the study have to collect necessary information for the process themselves as “background data”. Therefore there is a function in LCA software for adding and storing additional data in the database.

4.2.2 Inventory analysis function

The main function of LCA software in the Inventory analysis stage is to build up a product system flow (collection of unit processes) using unit process data in the database. ***Figure 9*** shows one example of a process tree, in this figure the final product (ACSR410, 1m) is made from several processes. To create this process tree, processes should be connected properly with each other. LCA software assists those performing LCA studies to connect these process data relatively by means such as “process data sheets *”, in which they can set up the relation of input/output volume for the processes.

* name for sheets used in LCA software (JEMAI)

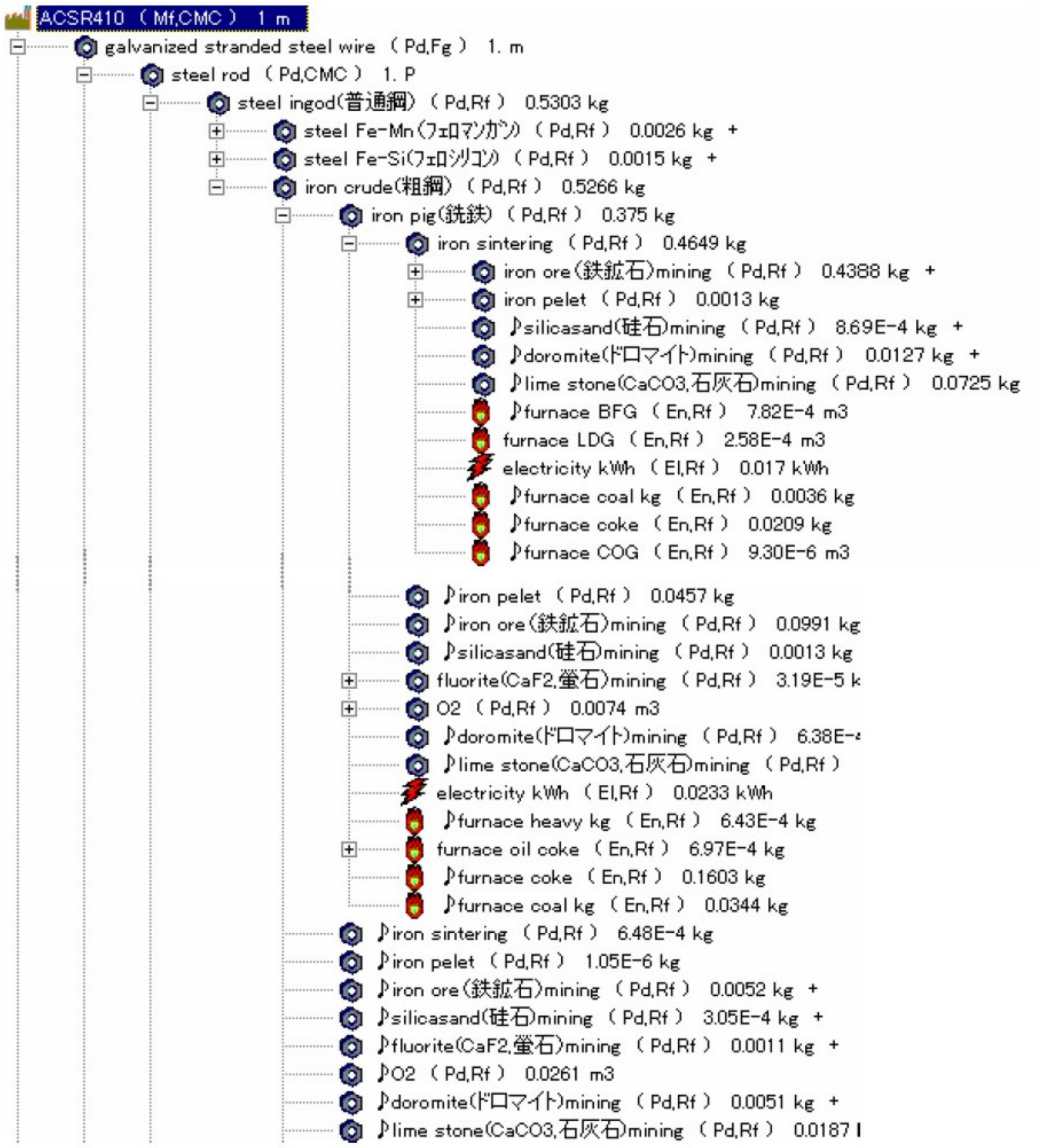

Figure 9: Process tree structure to produce ACSR 410mm^2 (part 1 of 2)

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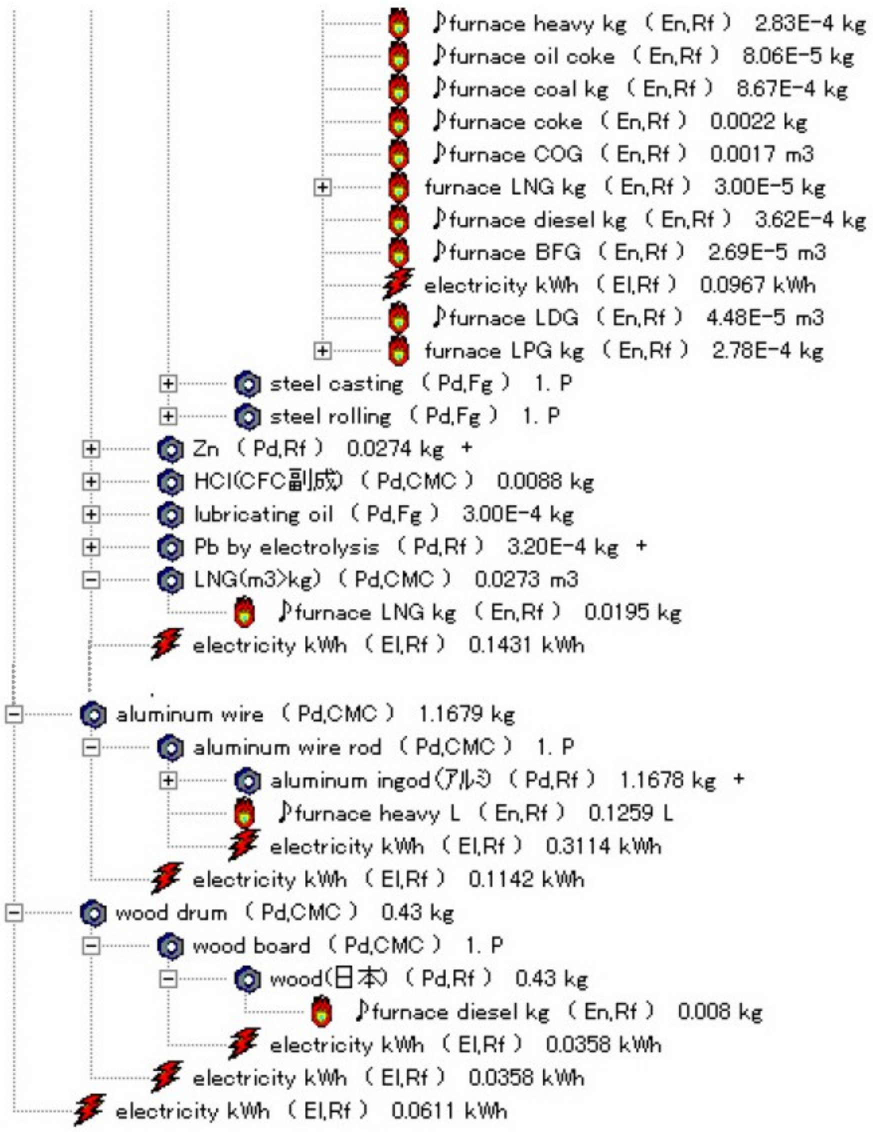


Figure 9: Process tree structure to produce ACSR 410mm^2 (part 2 of 2)

Once a product system flow is created, another indispensable function of LCA software is to calculate all the input/output for every unit process and to sum them up altogether through the entire product system. This calculation must be accomplished by normalising all the input/output for every unit process to the functional unit of the final product. If we conducted this calculation ourselves, it would require an enormous amount of work. However once a product system flow is created in LCA software, the software can calculate it with a click of the mouse. Results of the calculations are shown in the form of resource exhaustion volume, emission to air, emission to water, emission to ground, etc.

Another important function which should be mentioned is the allocation, because most industrial processes yield more than one product. A commonly used function for this allocation involves setting up a coefficient, which defines the ratio between the main product and co-products for each unit process. While the coefficient can be chosen based on the LCA study performers' assumption, often LCA software also has a function of sensitivity analysis in case the coefficient varies. Using this function, performers of LCA studies can relatively easily evaluate the influence of the coefficient they choose.

4.2.3 Impact assessment function

4.2.3.1 Category Indicator

After the Inventory analysis stage, we have to convert the "Inventory List" into "Environmental Impact" using category indicators. LCA software also supports calculation of environmental impact from the lifecycle inventory results using the database on category indicators. Although category indicators often vary according to the type of weighting method [see 4.2.3.2 Weighting Method] at the final stage, an example of them used in LCA software is shown below.

- Resource exhaustion → Inverse of total deposits in the world
- Global warming → Global Warming Potential (the IPCC 1992 report 100-year GWP)
- Acid rain → Acidification Potential: Leiden University Institute CML (CML Method)
- Ozone layer depletion → Ozone Depleting Potential (WMO-1991)
- Eutrophication of lakes and marshes → Leiden University Institute CML (CML Method)
- Toxicity to human body → Leiden University Institute CML (CML Method)
- Solid wastes → Weight (kg)

Each substance has different environmental impact potential to a certain impact category. This difference is adjusted by characterisation factors. LCA software has tables of characterisation factors for each category indicator.

Substance	SO_2	SOx	NO	NO_2	Nox	NH_3	HCl	HF
C. F.	1.0	1.0	1.07	0.7	0.7	1.88	0.88	1.6

C. F.: Characterisation Factor

Table 2: Characterisation Factor for Acidification potential

The above **Table 2** shows an example of characterisation factor (Acidification) stored in some software. LCA software packages can automatically calculate environmental impact from inventory results using category indicators and characterisation factors.

4.2.3.2 Weighting Method (Method for Integration)

There are several methods to aggregate weighted indicator results. LCA software also has a weighting function. Using these methods LCA software can calculate a single environmental impact indicator, which covers a wide range of impact categories. An outline of the four weighting methods ("**Eco-indicator 99**", "**Eco point 97**", "**EPS 2000**", "**NIRE-Dt**") are given hereafter.

Eco-indicator 99 [Netherlands]

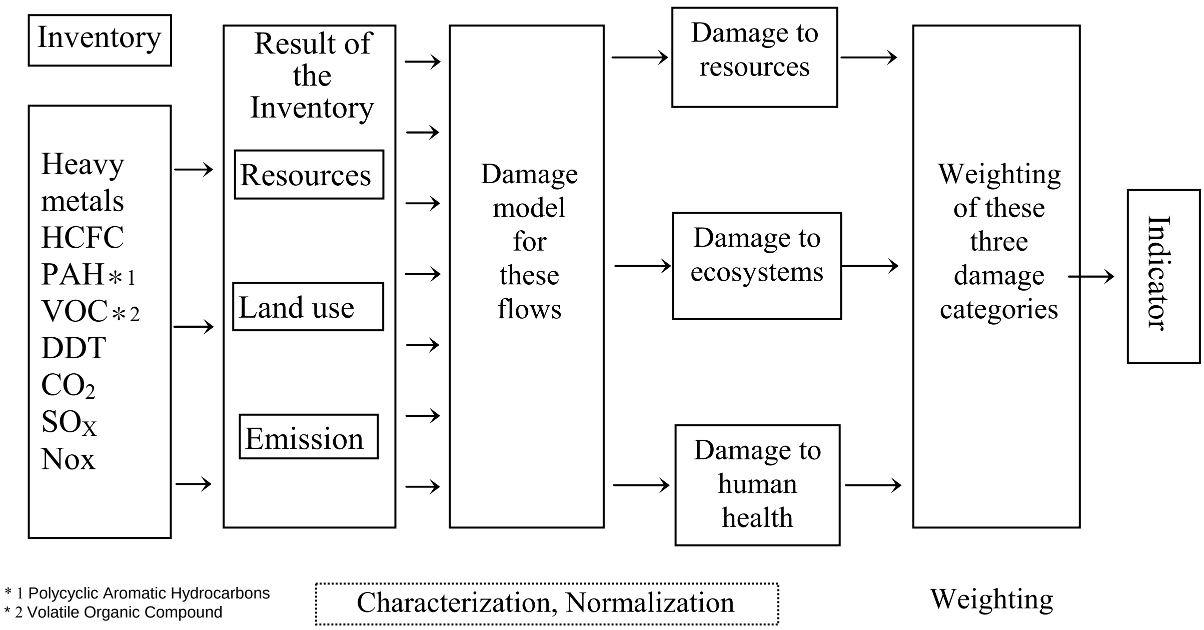


Figure 10: General procedure for the calculation of Eco-indicators

Substances are classified into three inventory categories and they become intermediate results for inventory analysis. There are three damage categories (Damage to resources, damage to ecosystems, and damage to human health), and inventory results are converted into the three damage categories by using several damage models for each category. Each damage model calculates the volume of damage to each category relating inventory results (volume of each emission, etc.) with various environmental effects. For example, HCFC emission → concentration ozone depletion substance → Damage to human health. Because of the uncertainties about the correctness of the model, Eco-indicator 99 has three versions (Hierarchist, Individualist, Egalitarian), which have different perspectives of the model.

The three damage categories are integrated into a single indicator through a weighting method in which damage to Human Health : Ecosystem Quality : Resources = 2:2:1.[19]

Eco point 97 [Switzerland]

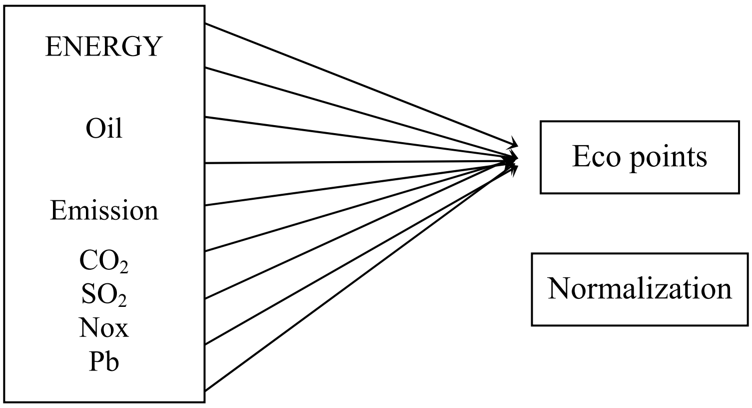


Figure 11: Image of calculation procedure for Eco point

Inventory results are directly converted and integrated into Eco points by the Eco factors. Samples of substances and Eco factors for each substance dealt with in Eco point is shown in **Table 5** (at the end of this section). Eco factor (EF) can be stated in its simple form as

$$EF=(1/F_M) \times (F/F_M).$$

F_M : Maximum allowable annual environmental load in Switzerland

F: Actual annual environmental load in Switzerland

EPS 2000 (Environmental Priority Strategy in Product Design) [Sweden]

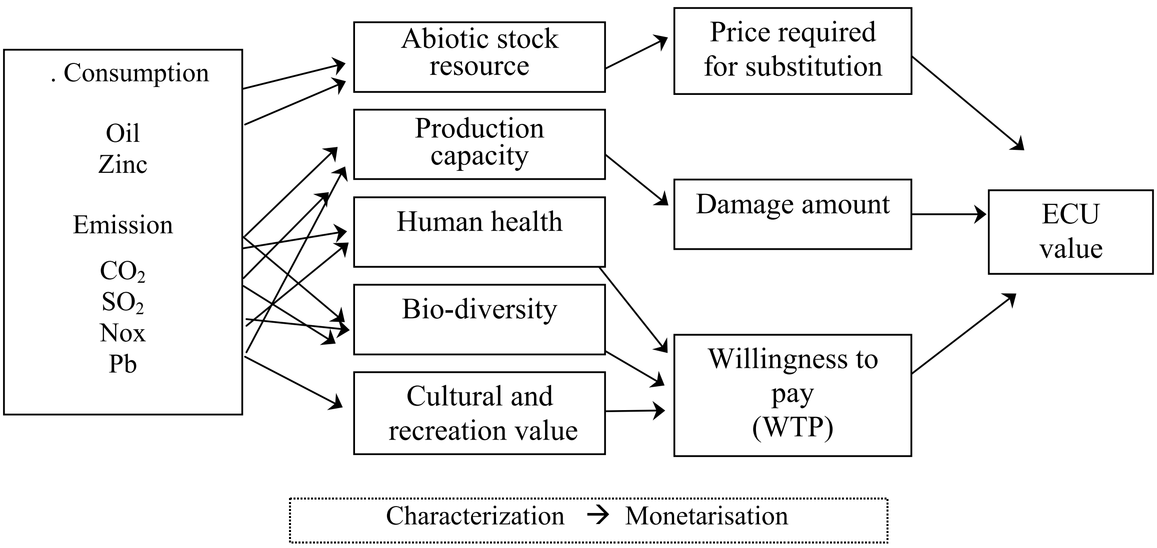


Figure 12: General procedure for the calculation of EPS

Substances are multiplied by characterisation factors to calculate category indicators for each impact category, and then the category indicators are converted into monetary value (Monetarisation). Category indicators are shown in **Table 6** (at the end of this section). There are five categories examined in the system (Cultural and recreation value is not taken into account in **Table 6**). The results for each category are finally added together into a single ECU value. 1 ELU is stated as

1 ELU (Environmental Load Unit) = 1 ECU (European Currency Unit).[20]

NIRE-Dt (National Institute of Resource and Environment) [Japan]

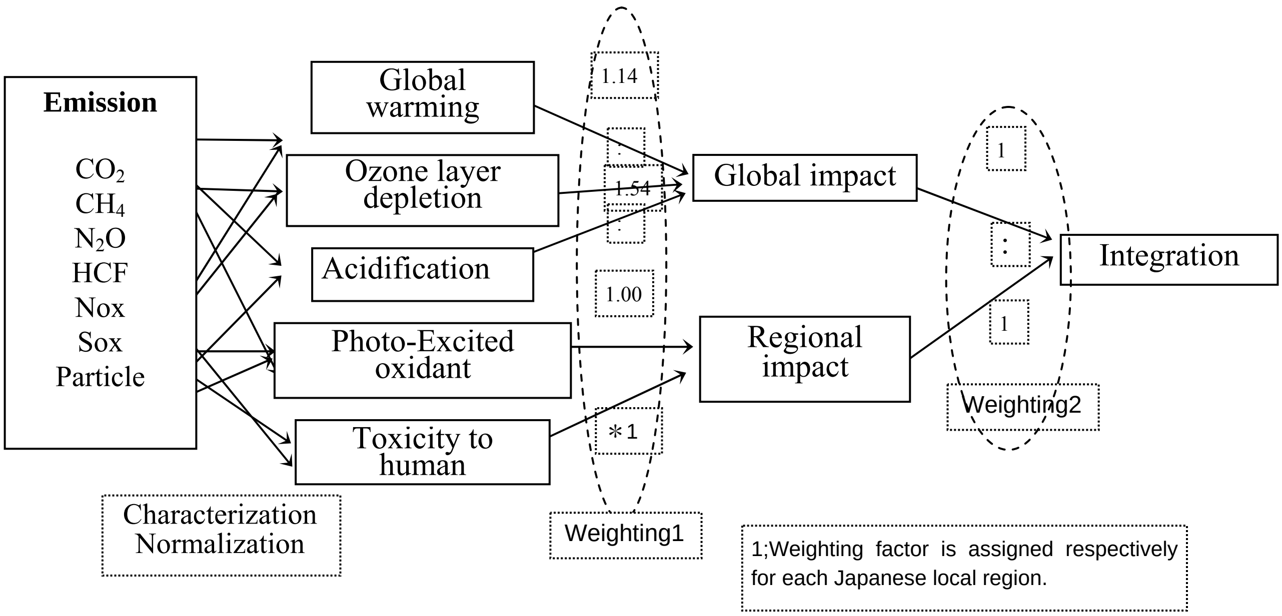


Figure 13: General procedure for the calculation of NIRE-Dt

Substances are classified into five impact categories and category indicators are calculated for each category. The category indicators are divided by reference values (the annual total emissions for all of Japan for each category) as a normalization procedure. The reference values are shown below in **Table 3**. Impact of Photo-Exited oxidant and Toxicity to humans is different between local regions in Japan; therefore reference values for them should be determined for each region. The table does not include these reference values. The normalised indicator results for each category are weighted by the factors shown in the above figure (weighting1) and are added together into two big categories (Global impact, Regional impact). Both are again added together into a final single indicator, after the weighting factor of 1 (weighting 2) is taken into account for both.

Impact category	Global warming	Ozone layer depletion	Acidification
Reference values	1.36E+12 (CO2 equiv. Kg)	1.86E+06 (CFC equiv. Kg)	2.21E+09 (SOx equiv. Kg)

Table 3: Reference values of MIRE-Dt

4.2.4 Analysis function

The ISO14040 series specify Interpretation as the last phase of an LCA study and also require that sensitivity analysis results should be reflected in the Interpretation phase. LCA software has support function for the sensitivity analysis. LCA research performers can assess the influence on environmental impact by using this function when they variously change the allocation ratio (such as ratio for co-product or recycle) for each process.

Another analysis function, which LCA software covers, is uncertainty analysis. Taking uncertainty of data for each process into account, LCA software has a function of maximum-minimum analysis and Monte Carlo method to carry out uncertainty analysis.

4.3 Conclusion and recommendation

As outlined throughout this chapter, each LCA software package has functions in common and they reduce time and labour for those performing LCA studies. However there are several functions which are different between LCA software packages and process data stored in each LCA software package is also different. Therefore it seems that consistent results cannot be obtained between different LCA software packages, and there is little meaning in comparing the final values of results derived from several different LCA software packages. Basic database, method of inventory calculation, impact assessment method, and weighting method may vary according to the software package. Therefore taking these differences between software packages into consideration, it is recommended that impact assessment comparison (such as a comparison between an original product and an improved one) should be carried out using the same LCA software.

In order to choose appropriate software for each LCA study, it is recommended an examination whether the function of the software as well as the database is suitable for the purpose of the intended LCA study. This should include examining whether the database of the software contains data which represents the conditions of the country or region in which the study is to be performed or not. Although development of criteria or rules to adequately select the software or show which software is appropriate for what kind of study would be beneficial. This would be extending the terms of reference and it will be left as a task for future work for others.

Software Name		JEMAI-LCA (Japan)	TEAM (France)	SimaPro (Netherlands)
Development Institution		Research Center for Life Cycle Assessment of the National Institute of Advanced Industrial Science and Technology (Former Agency of Industrial Science and Technology, National Institute for Resources and Environment) Japan Environmental Management Association for Industry	PwC Eco-bilan	PRe Consultants
Created		2000	1999	2001
Evaluated Edition		Ver. 1.1.3	Ver. 3.0	Ver. 5.0
Data Included		About 500 items	About 320 items	About 1,700 (Light version - IDEMAT, ETH-ESU compact, BUWAL250, Data archive, Industry data)
Main Source of Data Included	Material mining Material/product manufacturing	NEDO, RITE, Society of Chemical Engineers, Japan, "Investigation on the Analytical Method of the Total Ecobalance in Chemical Industry Products (II)" (1995) – Oil refining products CMC, "'94 Price and Cost of Japan-U.S. Chemicals" (1994) – Chemicals, synthetic resins Plastic Waste Management Institute, "Environmental Impact Assessment Report on how the Increase in the Amount Used of Plastic Products Affects the Earth Environment" (1993) – Resins Society of Chemical Engineers, Japan "Environmental impact assessment of foaming polystyrene and pulp mold in packing materials" (1993) – Oil refining products, resins Agency of Industrial Science and Technology, SRI, "LCA Inventory Data Preparation for Chemicals" (1998) NEDO, Fuji Research Institute, "Investigation on the Influence of Thermal Insulators on Global Warming" (1998) – CFCs, resins Japan Environmental Management Association for Industry, "Global Survey on Energy Use Rationalization Techniques in FY1994" (1995) – Ferrous metal and nonferrous metal manufacturing	APME, "Ecoprofiles" BUWAL250, "Life Cycle Inventory for Packagings" (1998) BUWAL132, "Ecobalance of Packaging Materials, State of 1990" (1991) ETH-ESU-Zurich, "Okoinventare von Energiesystemen" (1996)	APME, "Ecoprofiles of chemicals and polymers"(1999) – Plastics BUWAL250, "Life Cycle Inventory for Packagings" (1998) BUWAL132, "Ecobalance of Packaging Materials, State of 1990" (1991) Van den Bergh en Jurgens (1991) ETH-ESU-Zurich, "Oko-inventare von Energiesystemen" (1996) Charmers, "Packaging and the environment" (1991) Delft Univ, "Bouwmaterialen en Milieu" (1993) – Cement Van Heijningen, "Meer energiekentallen in relatie tot preventie en hergebruik van afvalstromen" (RIVM, 1992) Holtzatlas, Wagenfuhr R., Scheiber C (1974) – Wood I DEMAT, "Full database for material information for design and construction purposes"(2001) – Nonferrous metals

Software Name		JEMAI-LCA (Japan)	TEAM (France)	SimaPro (Netherlands)
Main Source of Data Included (cont'd)	(cont'd) Material mining Material/product manufacturing	Chemistry Economic Research Institute, "Energy Analysis Investigation Report of Basic Materials" (1993) – Aluminums National Institute of Resources, "Investigation Report on the Use and Supply of Fine-ceramic Resources"(1988) – Rare metals Agency of Industrial Science and Technology (Fuji Research Institute Corp.), "Data Collection of Iron, Copper and Aluminum Production Overseas and Transport" (1996) – Copper and bauxite mining and transport Agency of Industrial Science and Technology (Narita), "Life Cycle Assessment of Zinc Recovery from Electric Furnace Dust" (2000) Agency of Industrial Science and Technology (Narita), "Inventory Analysis of Domestic Lead Production" (2000) Agency of Industrial Science and Technology (Sugita), "Research on Life Cycle Inventory Analysis of Household Electrical Appliances" (1999)		R. B. J. Kemna; TU Delft; The Netherlands, "Energiebewust ontwerpen" (1981) – Processes of ferrous metals/nonferrous metals Diehl, M. Sc. Thesis, "Life cycle assessment of cotton" (Delft Univ., 1994) – Cottons P. F. Chapman and F. Roberts, "Metal Resources and Energy" (1983) – Ferrous metals/nonferrous metals "Metals and Minerals Yearbook" (1999) – Ferrous metals/nonferrous metals Yoshiki et al., "Metals production" (Journal of Metals, 1993) – Ferrous metals/nonferrous metals SPIN: Booij H., "Produktie van chloor" (RIVM, 1993) – Chemicals Loos B., "De produktie van glas, glasvezel en glaswol" (RIVM, 1992) – Glasses RIVM, "Productie van primair ijzer en staal" (SPIN Report, 1992) – Ferrous metals PRe Consultants data collection (Dutch Cement Industry Association) WNH, "Importgegevens hardhout en amerikaans naaldhout" (1994) – Woods IEA, "World Resources 2000-2001" (2000)

Software Name		JEMAI-LCA (Japan)	TEAM (France)	SimaPro (Netherlands)
Main Source of Data Included	Transport	Plastic Waste Management Institute, “Global Environmental Impact Assessment Report on the increase in the amount of plastic products used” (1993) BUWAL132, Conversion of “Ecobalance of Packaging Materials, State of 1990” (1991)	ETH-ESU-Zurich, “Okoinventare von Energiesystemen” (1996) “SNCF et l’environnement” ETH-ESU-Zurich, “Laboratorium fur Energiesysteme” (1996) International Civil Aviation Organization	Charmers, “Packaging and the environment” (1991) ETH-ESU-Zurich, “Oko-inventare von Energiesystemen” (1996) ETH-ESU-Zurich, “Oko-inventare fur Energiesysteme” (1994) IEA, “World Resources 2000-2001” (2000)
	Energy (electric power/ fossil fuel firing, etc.)	Matsuno, et al., “Life Cycle Inventory of the Receiving End Standard of the Ten Electric Power Companies in Japan” (1998) – Electric power emission factor by area, and coal, crude oil and LNG burning power generation factor BUWAL132, “Ecobalance of Packaging Materials, State of 1990” (1991) – Nuclear Power Generation, Overseas Coal/Oil/Natural Gas Burning Power Generation and Fossil Fuel Fired Power Generation Agency of Industrial Science and Technology, “Inventory Data on Overseas Coal Used in Japan” (2000) Institute of Energy Economics, Japan, “Life Cycle Inventory Analysis on Fossil Energy in Japan” (1999) - Crude oil, natural gas and LNG production Japan Environmental Management Association for Industry “Global Survey for Energy Use Rationalization Techniques in FY1994” (1995) – Coke manufacturing and burning” (1995)	ETH-ESU-Zurich, “Okoinventare von Energiesystemen” (1996) BUWAL132, “Ecobalance of Packaging Materials, State of 1990” (1991)	ETH-ESU-Zurich, “Oko-inventare von Energiesystemen” (1996) BUWAL132, “Ecobalance of Packaging Materials, State of 1990” (1991) RIVM, “Inventory of Aircraft Emissions” (1991) - Airplanes RIVM, “Energieverbruik vrachtvervoer” (1987) -Trains W. Packard, “Sea-trading, Vol. 1” (Fairplay Publications, 1984) – Ships CBS, “Luchtverontreiniging Wegverkeer” (1992) RIVM, “Energiegebruik in Verkeer en Vervoer” (1989)
	Waste	Atsushi Inaba, “Life Cycle Inventory of a Refrigerator”, Environmental Management, Vol.31, No.7 (1995) Agency of Industrial Science and Technology (Narita), “ Life Cycle Assessment of Zinc Recovery from Electric Furnace Dust” (2000)	BUWAL250, “Life Cycle Inventory for Packagings” (1998) ETH-ESU-Zurich, “Laboratorium fur Energiesysteme”(1996)	PRe Consultants data collection (Dutch Waste Communication) Dutch Waste Communication, “Materiaalhergebruik, een verkenning” (1993) Pre Consultants data collection (AUMUND FORDERTECHNIK) (1994) Centrum voor Energiebesparing en schone technologie, “Verwijdering van huishoudelijk kunststofafval, analyse van milieu-effecten en kosten” (Delft Univ 1994) – Recycle

Software Name		JEMAI-LCA (Japan)	TEAM (France)	SimaPro (Netherlands)
Major Contents of Data Included (regarding ACSR)	Aluminum	Alumina Ingots Sheets Secondary aluminum metal	Alumina Ingots Sheets Aluminum product (100% recycling)	Aluminum related data: 36 items (including 22 types of alloys) Aluminum mold process data: 46 items (including alloys) Aluminum recycling: 0%, 25%, 50%, 80%, 100% (2 items) Ingots: 2 items, Foils: 4 items, Lumps, Alumina
	Material mining Material/ product manufacturing	Pig-iron, Crude steel Common steel ingot, Cold-rolled steel plate Hot-dip zinc-coated carbon steel sheet Electrolytic zinc-coated carbon steel sheet, Electric steel Flat rolled magnetic steel sheet (2 items), Stainless-steel plate	Steel plate Steel plate (100% recycling) Tinned Plate Tinned Plate (100% recycling) Tinned Plate (100% recycling, uncoated)	Steel related data: 138 items (IDEMAT 105 items, other 33 items) Steel mold process related data: about 10 items Iron, iron plate: 9 items (excluding IDEMAT) Tin plate: 13 items (excluding IDEMAT)
	Wood	Raw wood (overseas), raw wood (Japan)	No data for wood products	103 items of data by kind of tree for wood product
	Electric Power	By country: 67 countries (OECD Statistics are used to determine the electric power configuration except for Japan. Factor by power generation type is common to each country) By power generation type: 5 types (nuclear power, hydroelectric power, oil fired power, coal fired power, and LNG fire power) By domestic area: 9 (by each electric power company)	By country: 35 countries (OECD Statistics are used to determine the electric power configuration except for France. Factor by power generation type is common to each country) For industry: Four processes	By country: 17 countries (mainly West European countries) By power generation type: about 80 items By generation voltage: about 80 items

Software Name			JEMAI-LCA (Japan)	TEAM (France)	SimaPro (Netherlands)
	Transport (number and content of data are indicated by institution.)		Automobiles: 5 (5 types of trucks) Ships: 4 (special cargo ship, tanker, LNG tanker, ferry) Japan is divided into 9 areas, and the distance between each area is stored as data.	Railroads: 4 (average in France, diesel locomotive, electric train, average in Europe) Automobiles: 12 (diesel (2 types), unleaded gasoline, leaded gasoline, truck (7 types), van) Ship: 2 (tanker, river barge) Airplanes: 2 (long distance, cargo plane)	Railroads: 8 (average in western Europe 2, electric train 3, average for electric train/diesel locomotive, item including equipment 2) Automobiles: 31 (bus 1, diesel car 1, LPG-driven car 1, gasoline-driven car 2, van 4, moped 1, autobicycle 1, privately-owned car 3, tractor 1, trailer 1, truck 15) Ships: 23 (barge 1, bulk carrier 2, vessel for coast 4, vessel for ocean 1, bulk tanker 2, cargo ship 4, inland vessels 1, LNG taker 1, sea ship 1, tanker 6) Airplanes: 2, Pipelines: 1
	Waste		6 items (CFC treatment (2 kinds), lead battery treatment, landfill, crushing, leachate treatment)	18 items (Incineration 3, reclamation 15)	Waste process data is set up by material and is automatically determined by setting the material and the scenario. There are 127 waste process items (incineration 55, reclamation 23, recycling 27, other 22).
Impact Assessment Method Included	Method by Category	Global Warming	IPCC (1992) (100 yrs/50 yrs/20 yrs) IPCC (1995) (100 yrs)	IPCC (1992) (GWP 100 yrs, 50 yrs, 20 yrs)	CML, CML2 baseline 2000 (IPCC (1922)) (GWP 100 yrs, 50 yrs, 20 yrs)
		Ozone Layer Depletion	WMO (ODP)	WMO (ODP)	CML, CML2 baseline 2000 (WMO (ODP))
		Acidification	CML (AP)	ETH (AP)	CML, CML2 baseline 2000
		Neutrofication	CML (NP)	CML (NP)	CML, CML2 baseline 2000
		Photochemical Oxidant	CML (UNECE) (POCP)	WMO (POCP)	CML, CML2 baseline 2000 (UNECE) (POCP)

Software Name			JEMAI-LCA (Japan)	TEAM (France)	SimaPro (Netherlands)
Impact Assessment Method Included	Method by Category	Human Toxicity	CML	CML, CST, USES 2.0, USES	CML, CML2 baseline 2000 (USES)
		Ecosystem Damage	CML	CML (terrestrial ecosystem toxicity, water ecosystem impact), CST (terrestrial ecosystem toxicity, underwater ecosystem impact) USES 2.0 (terrestrial ecosystem toxicity, underwater ecosystem toxicity based on sediments), USES (terrestrial ecosystem toxicity, water ecosystem toxicity)	CML, CML2 baseline 2000 (USES)
		Exhaustible Resources	Evaluate using a reciprocal of deposits as a factor.	CML, EB	CML, CML2 baseline 2000
		Other	Energy consumption: Evaluate using calorific value per unit weight as a factor. Amount of solid waste discharge: Evaluate discharge weight as it is.		Exhausted biological resources: CML2 baseline 2000 (Abiotic Depletion Factor)
	Integrated Impact Assessment		Eco-Indicator '95 EPS (1997) Ecopoints Distance to Target (Dt) method of the Agency of Industrial Science and Technology	Eco-Indicator' 95 EPS (1997) Ecopoints CVCH	Eco-indicator '99 Eco-indicator '95 EPS (2000) Ecopoints
Allocation			The allocation method for such as weight is included as a function. The user can allocate by the allocation method selected in each process. Only one allocation method within a process is available and it should be consistently used. The user can easily allocate the material data stored.	Can set up different factor for default allocation factor in the processes. It is not bound by the allocation method (weight allocation, money allocation), etc. Allocation factor can be set up for every input/output item within the same process (the allocation method consistency depends on the user).	Can set up different factor for default allocation factor in the processes. It is not bound by the allocation method (weight allocation, money allocation), etc. Allocation factor can be set up for every input/output item within the same process (the allocation method consistency depends on the user).

Software Name	JEMAI-LCA (Japan)	TEAM (France)	SimaPro (Netherlands)
Overseas Manufacturing	Overseas data is attached importance as much as possible (overseas land transport, etc.) regarding an overseas production process. Even if technology of Japan is applied, overseas electric power generation ratio is used to prepare the data (aluminum refinement, mining data, etc.). When a source country and an import ratio change, the user can modify the data by changing the electric power generation ratio into that of the source country.	For material imported to European countries, the overseas process data, which considers overseas technology, is applied. (iron and aluminum are from BUWAL250) The data is from specific source countries and does not cover the change of countries or the import ratio.	For material imported to Europe and the U.S., the overseas process (iron and aluminum have two or more items including BUWAL250), which considers overseas technology, is applied. The data is from specific source countries and does not cover the change of countries or the import ratio. However, by preparing the data of different source country, the user can create the data covering the change of countries and the import ratio.
Marine Transport	For material data, marine transport is taken into account by setting the transport distance and means from the source country on the assumption that the material is imported to Japan.	For material data, marine transport is taken into account by setting concrete transport distances and means on the assumption that the material is imported to European countries. The data is from specific source countries and does not correspond to the change of the countries or the import ratio.	For material data, marine transport is taken into account by setting concrete transport distances and means on the assumption that the material is imported to Europe and the U.S. The data is from specific source countries and does not cover the change of countries or the import ratio. However, by preparing the data of different source country, the user can create the data covering the change of countries and the import ratio.
System boundary	Data includes from mining; lower accuracy	Data includes from mining	Data includes from mining
Overseas (Outside of Japan) Technology	In some data, technology in Japan is applied with adjustment of the electric power generation ratio.	Data, which considers overseas technology, is used	Data, which considers overseas technology, is used
Import Country Change	Only by inputting ‘ratio’	User must retrieve the distance and technical data, etc. and create the data again	Relatively easily covered by collecting distance/technical data, etc. by country

Table 4: Comparison of Software Characteristics/Features

Item	Actual annual environmental load in Switzerland		Maximum allowable annual environmental load in Switzerland		Eco Factor	
	volume	unit	volume	unit	volume	unit
Emission to air						
Nox	136,000	ton/year	45,000	ton/year	67	g^{-1}
SO2	34,300	ton/year	25,400	ton/year	53	g^{-1}
NMVOC	211,000	ton/year	81,000	ton/year	32	g^{-1}
NH3	70,700	ton/year	33,400	ton/year	63	g^{-1}
PM10	36,000	ton/year	18,000	ton/year	110	g^{-1}
CO2	44,200,000	ton/year	15,000,000	ton/year	0.2	g^{-1}
CH4	237,000	ton/year	---	ton/year	4.2	g^{-1}
Emission to water						
COD	115,000	ton/year	140,000	ton/year	5.9	g^{-1}
P	2,900	ton/year	1,200	ton/year	2,000	g^{-1}
N total	40,000	ton/year	24,000	ton/year	69	g^{-1}
Cr	38	ton/year	240	ton/year	660	g^{-1}
Zn	188	ton/year	940	ton/year	210	g^{-1}
Cu	71	ton/year	240	ton/year	1,200	g^{-1}
Cd	0.94	ton/year	9.4	ton/year	11,000	g^{-1}
Emission to underground water						
NO3	150,000	ton/year	75,000	ton/year	27	g^{-1}
Agricultural chemical	1,800	ton/year	1,500	ton/year	800	g^{-1}
Harmless landfill	3,030,000	ton/year	2,430,000	ton/year	0.5	g^{-1}
Underground landfill	41,000	ton/year	41,000	ton/year	24	g^{-1}
Low level radioactive waste	1,190	m^3/year	600	m^3/year	3,300	cm^{-3}
High level radioactive waste	85	m^3/year	43	m^3/year	46,000	cm^{-3}
Preliminary energy consumption	1,027,000	TJ/year	1,012,000	TJ/year	1	MJ^{-1}

Table 5: Eco Factor used in Eco Point

Impact Category	Protection Category	Unit	Notes
Life expectancy	Human Health	personyear	
Severe morbidity and suffering	Human Health	personyear	Including starvation
Morbidity	Human Health	personyear	Like a cold or flue
Severe nuisance	Human Health	personyear	Would normally cause a reaction to avoid the nuisance
Nuisance	Human Health	personyear	Irritating, but not causing any direct action
Crop production capacity	Production Capacity	kg	Weight at harvest
Wood production capacity	Production Capacity	kg	Dry weight basis
Fish & meat production capacity	Production Capacity	kg	Full weight of animals
Base cat-ion capacity	Production Capacity	H+ mole equivalents	Used only when models including the other indicators is not available
Production capacity for water irrigation water)	Production Capacity	kg	Must be acceptable for irrigation, e.x. with respect to persistent toxic substances
Production capacity for water drinking water)	Production Capacity	kg	Fullfilling WHO criteria on drinking water(1997)
Depletion of element reserves (for each element)	Abiotic stock resource	kg of elemet	E.g. Cu reserves, kg Cu
Depletion of fossil reserves (Natural gas)	Abiotic stock resource	kg	The hydrocarbon part
Depletion of fossil reserves (Oil)	Abiotic stock resource	kg	
Depletion of fossil reserves (Coal)	Abiotic stock resource	kg	
Depletion of mineral reserves (for each mineral)	Abiotic stock resource	kg	
Extinction of species	Bio-diversity	Dimension-less	The normalisation is made with respect to the species extinct during 1990

Table 6: Category indicators used in EPS

5. LIFE CYCLE ASSESSMENT, OVERVIEW FOR OHL COMPONENTS

5.1 Structures, Foundations and Earthing Systems

5.1.1 Lattice Steel Towers and Steel Poles

5.1.1.1 Production

Raw material for lattice towers and steel poles consists of steel in standard qualities. A certain amount of scrap material may be added during the melting process. The production is a standard procedure for steel works.

Lattice towers: Members consist of angles in dimensions from 40x40x4 mm up to approximately. 250x250x24 mm. Fabrication is carried out using CNC machines which cut, crop, mark and punch (up to a certain diameter). In the case of extreme dimensions of towers (e.g. 1000kV-line in Japan) legs and bracings can be made of tubes. Tubes were also sometimes used on older lines.

Steel poles: Raw material for steel poles is sheet steel which is rolled for tubes or bent for octagonal cross sections. Depending on the length of the pole, the body may consist of one single part or of sections which are connected during erection work on site. Cross-arms come in tubular form or maybe lattice structures.

5.1.1.2 Corrosion protection

General [21]

Corrosion protection, in particular the heavy-duty corrosion protection must take into account all the facts concerning the objects to be protected. From the thermodynamic point of view, steel is obtained from ore, its original form, through the addition of heat and it wants to return to this original form by means of rusting or corrosion. The reasons for corrosion are chemical or electrochemical processes, e.g. in the presence of oxygen and water as well as through attacks by aggressive media, such as SO_2 under conditions of high humidity, which result in the formation of sulphurous acid (H_2SO_3) and consequently in a destruction of the metallic surface. Without surface protection, corrosion leads to complete destruction of the material. All parts of transmission lines made of steel therefore need protection against corrosion. Corrosion protection cannot cure damage which has already occurred on structures. Protection against corrosion may have an important influence on the environment.

Rusting steel

Rusting of steel leads to a reduction of thickness of the material and may lead to corrosion problems of connecting bolts, yoke plates, etc. In some countries special alloys of rusting steel Cor-Ten - weathering steel, Mayari R, Republic 70, Yoloy-E-HS, (USA), ROM-COR 52 B (SRR), HI-YAW-TEN, Cor-Ten A, B, C (Japan), Atmofix (NOR, CSSR), KT-korrosionsträger Stahl, St35/50 (former DDR), were used. Additives of copper, sulphur, chrome and nickel were found to reduce the speed of the rusting process. The first experience in the USA is from 1933. The oxidation products from rust were supposed to protect the steel and to prevent further reduction of the members' thickness. The results were not as expected and many of those structures are now being coated on site or even rebuilt with remarkable financial and technical efforts.

The main problems were corrosion in the connecting joints and splice plates:

- under heavily polluted conditions
- in areas with high humidity
- on structures with vegetation not removed from the tower bodies´ base

In some cases pack-rust has affected the joints and bolts.

Protection by red lead

Red lead was used for protection in Europe until about the 1950s. The material was applied on the structures on site as a maintenance coating. The disadvantage of this method is pollution of the soil and air by lead during application and as a result of the reduction of coating material. Protection by red lead was therefore replaced by other methods.

Protection by galvanising

In the late 1950s many utilities proceeded to change the corrosion protection they had used up to that time and adopted hot dip galvanising of all elements. The galvanising protects the entire tower by acting as a reactive anode.

It is only a matter of time and atmospheric influence until the iron-zinc alloy layer of the hot galvanising is used up. When this occurs the destruction of the metallic blank surface starts with full effect.

Zinc can be washed out from galvanised surfaces by rainwater. Emission to the soil is highly localised in the vicinity of galvanised structures. The release of zinc to the environment can be reduced when galvanised structures are coated. Zinc contains cadmium as natural pollution in the raw material and the amount is dependent on the quality of the zinc. The amount of cadmium in zinc has been reduced dramatically since the 1970s. [22]

0	Material steel	
1	Gamma layer	21.0 - 28 % iron content
2	Delta layer	7.0 - 12.0% iron content
3	Zeta layer	5.8 - 6.2% iron content
4	Eta layer	0 %, pure zinc iron content

Table 7: Structures of the iron-zinc alloy layer

Protection by coating on site

In principle coatings may have the following purposes i) to protect the structures against corrosion, ii) to prevent release of zinc into the environment iii) to give structures a desired colour (red-white-red aircraft warning, camouflage-green, etc.)

Maintenance coatings can be a first treatment (some years after erection of the line) on galvanised surfaces or can be repeat treatments.

Cleaning of towers: Before destruction of the zinc gamma layer take place (see table above), an effective additional corrosion protection has to be applied by means of one or several layers of anticorrosion paint. Cleaning of the corroded tower parts is required before coating. For reasons of environmental protection this removal of rust can be carried out mechanically with jet devices or chemically by pickling when the tower is wrapped, or can be performed manually by means of wire brushes or synthetic abrasives. Of course, the time expenditure is very high, which is reflected in the costs.

Base coat on site: Once the steel tower has been cleaned for the base coat, preservation works have to start immediately. Any delay would allow the formation of rust films that would prevent coating. In the past lead oxide red (Pb_3O_4), calcium plumbate ($2CaO\ PbO_2$) as well as zinc phosphate (PO4)2. have been proven to be ideal for the base coat. Red lead oxide with its alkaline passivation effect on acidic atmospheric components which are transformed to non-corroding compounds, has shown particularly positive results. (Chromates combined with iron oxide or zinc oxide also offer good protection, but normally are not being used by utilities).

Top coat on site: Top coats can be applied in several layers depending on the environmental conditions and other influences. They are referred to as Top I, Top II, etc. Where the supports are exposed to extreme weathering and high mechanical stress, coating materials of mainly PVC basis and water-soluble materials (free of solvents) are now being used.

PVC: PVC binder with its comparatively wide range of elasticity allows for a large degree of absorption of the mechanical stress factors that influence towers. On the other hand, addition of acrylic resin allows for fast drying permitting quick reworking of the first top coat. The desired layer thickness when dry amounts to some 40-60 µm per coating. This results in a total coating thickness of some 160-180 µm.

Double component coats: All the before mentioned materials are single-component coats drying on an oxidation basis and provided with solvents. Double-component coats, such as epoxy resins (EP) or unsaturated polyester resins (UP) as well as polyurethane (PU) are subject to chemical drying processes which considerably complicate processing at the construction site (pot life of 15-45 minutes, which means that after that time the resin-accelerator mixture can not be further processed as the drying has already been completed).

Water soluble coating materials: In the early 1990s water soluble materials were developed, free of solvents. Their use was triggered by regulations in some countries to reduce the use of solvents. These materials can be applied by airless methods for both methods: in-factory-Duplex and coating on site.

Impacts on the environment: When painting on site, impacts must be expected from preparation works on the tower members surfaces (cleaning of towers) and from losses of painting material. Screening of towers and fencing may be necessary. Pollution of soil by zinc from galvanised material must be expected if a coating layer is not present.

Protection by in-factory-coating

Another possibility of heavy duty corrosion protection is the in-factory-method. Materials based on PVC or water-soluble materials are applied on hot surfaces of the tower members before erection and before being transported on site. Thus the former basic rule saying that hot galvanised surfaces need weathering or zinc patina before they can be coated, may be dismissed.

This application is the so called „Duplex system“. The basic idea behind this system consists of the combination of hot galvanising and in-factory-coating which results in a state called synergism. Both systems, hot galvanising and coating, are not looked at separately as far as the duration of their protection is concerned, but they are added and multiplied by a factor of 1.5. This results in an increase in the life of the corrosion protection of approx. 50 % compared to traditional methods of protection.

Application of the Duplex System: The desired dry layer thickness can be applied by means of airless coating machines. The process is carried out under permanent control in the factory and losses of coating material therefore can be reduced to a minimum.

As all coating works are carried out inside, this allows for complete independence from the weather conditions. Preconditioned coating defects, which often occur on objects situated outdoors (too high humidity and too low an object temperature resulting in a fall below the dew point and moisture in the coating film) can be eliminated completely.

Impacts on the environment: As in-factory-coating is carried out in closed areas, minimal impacts on the environment are expected during the process of application. This concerns preparation work of galvanised tower members as well as coating works itself. Pollution of soil by zinc from galvanised material is reduced as long as the coating layer is present.

5.1.1.3 Dismantling and recycling of lattice steel towers and steel poles

Dismantling

Lattice towers normally are dismantled either by undoing their bolts or by cutting their members on site. Steel poles are separated into their construction sections or are cut on site. A typical length of such scrap metal is between 0.7m and 1.5m.

Recycling

Recycling of metallic structures is not imposed by law in each country but is common practice in very high percentage of countries. The material is considered to be raw material with good value. Sometimes used parts are stored for emergency structures or are reassembled for new lines.

All salvage from steel towers can be recycled. In principle three classes of scrap steel may be distinguished.

- ***Rusted metal without galvanizing or paint***: highly appreciated quality, can be melted without special considerations
- ***Galvanised steel***: can be melted easily, the amount of such galvanised material going to general scrap metal is limited. A special process is necessary to recycle zinc.
- ***Coated/Painted steel***: can be melted under certain conditions and with special treatment. Good experience is available worldwide e.g. from recycling of ships (especially hulls).
- ***Recycling of zinc*** may be expected for up to 90% of galvanised surfaces.

Even if some special considerations are necessary when recycling painted members of towers, all metallic parts can be recycled. The quality of scrap metal influences the price achieved. Special measures are necessary when synthetic materials must be recycled, but such materials are not normally used on structures.

5.1.2 Wooden Poles

5.1.2.1 Production

Wooden poles are made from complete trees or laminated wood, depending on the tower configuration and mechanical loads from conductors. Larches or pine trees are typical trees from alpine regions used for poles. Douglas Fir is a common species in North West Europe. Timber work is normally done during the winter season and the timber needs some time for the drying process before being treated in the preservation factory.

Wooden poles can be embedded into soil directly or by wooden grillage systems or may be fixed by concrete foundations. Lifetime of impregnated wood and the lifetime of concrete footing may be estimated to be roughly equal.

5.1.2.2 Preservation

Wooden poles without any preservation could be attacked by fungi, animal or phytogenic parasites and would rot down within a short period of time. The transition section from soil to air needs special protection (it may be estimated that approximately 90% of all damages on poles are in this section). Various methods exist to protect wood and experience about advantages and disadvantages has been gained over decades. In principle several methods can be distinguished

- preservation based on salty emulsions with additives (chrome, copper, arsenic, etc.)
- preservation by creosote
- preservation by tar-based oil

Conservation by *salty emulsions* has led to considerable discussion about the preservation materials in such emulsions, especially related to chrome and arsenic. It may be estimated that approximately 10% of the applied amount of arsenic will reach the soil. During maintenance poles preserved by salty emulsions are treated by injecting additional emulsion to extend life.

Creosote as a preservation material shows a tendency to replace the salty emulsion methods. It is estimated that 1/3 of the material disappears into air and soil during the lifetime of a wooden pole. The amount of creosote used per pole has been reduced remarkably since the mid 1990s.

Preservation by tar-based oil has a long tradition in the business of wooden poles. Despite newly developed methods (creosote or salty emulsions), tar based oils show a certain revival. Maintenance preservation with tar-based oil is treated by new coating.

Newly developed materials *based on organic substances* have a limited durability compared with inorganic materials (all organic materials are destroyed, depending on the time)

Water soluble preservation materials need a fixing procedure to prevent soaking into soil or waters.

Nevertheless all kind of protection material disappears after some years and the protection must be renewed. This is caused by washing out from rain or humidity from the ground.

Wooden poles must be checked periodically. Typical values for such intervals depend on the importance of the line and the voltage level and are between 5 and 10 years. Checks of directly embedded poles are done by excavating approximately 0.5m. Testing methods using ultrasonic have been developed. Another method is to measure density and biological constitution of the pole near the soil by electrodes (‘Polux’).

5.1.2.3 Dismantling and recycling of wooden poles

Dismantling

Efforts needed in dismantling wooden poles are very small compared to those for towers made of steel or concrete. Used poles normally show damage areas only in the transition section from soil to air and therefore can be used for many other purposes.

Recycling

The main idea is to recycle or reuse used poles instead of burning them. Used wooden poles can be given to landowners for free, they use them for fences, structural and other purposes. Landowners have to sign a contract in which they confirm their acceptance of risks from preservation materials in the poles, if any. Other applications for used poles are paddocks, supporting pillars for scaffolds, retaining walls in road construction, landfill, road barriers, small bridges, etc. In some countries the demand for such poles cannot be met by the utilities. Some utilities store poles in stock for emergency structures.

Waste from wooden poles is collected by the utilities as salvage and is very small. This salvage is brought to disposal facilities. Pilot projects are established to gain cellulose, insulating fibres, etc. Methods for decontamination of salt-preserved and tar-oil-preserved poles based on chemical, biological and micro-biological principles are established but some are only in the development stage or at laboratory experimental stage. Parts treated with creosote or other preservation materials are not for use for civil purposes. Waste from such impregnated parts is chipped and burned in appropriate plants.

Recycling of wooden poles is only imposed by law in very few countries and recycling of wooden poles which cannot be reused is not common practice. If recycled, the overall rate of recycling (reuse and recycling) may be in the range between 50% and 100%.

5.1.3 Concrete Poles

5.1.3.1 Production

Concrete poles are produced either by a centrifugal method or by moulding. The first method leads to poles which can withstand high mechanical loads and are applicable for voltage levels of 110kV and above whilst the second method is best suited for medium and low voltage grids. Centrifugal poles are produced in factories, moulded poles can even be produced on site, provided an experienced and reliable process and reliable site control are used.

All concrete poles are reinforced. Crossarms are made of concrete or steel. Concrete poles can be embedded into the ground directly or can be installed using foundations. Colouring of concrete poles (e.g. for environmental reasons) is rare but is the practice in some countries in certain regions.

5.1.3.2 Preservation

In general no preservation measures for concrete poles are necessary if they have been produced properly. If these are necessary however, such measures follow the same procedures as for concrete foundations.

5.1.3.3 Dismantling and recycling of concrete poles

Dismantling

Dismantling of concrete poles is in the first place a mechanical problem. The structures normally are cut down on site and are brought to recycling plants, or are crushed on site. It is frequently the practice to bring poles which are as complete as possible to the plant.

Recycling

Recycling of concrete poles is not imposed by law in each country but is common practice. If poles are recycled the degree of recycling can reach high percentages.

In modern recycling plants 100% of concrete poles can be recycled. Recycling plants have several advantages for the environment such as

- a contained process
- minimised emissions of noise (containment)
- no emissions of dust (use of filters)
- optimised separation of recycled material

The first step is to separate the reinforcing steel from the concrete by using wrecking balls, big size tongs or other mechanical methods.

The separated reinforcing steel is a highly appreciated quality and can be recycled without special considerations. It follows the same considerations as steel from lattice towers.

The concrete material is ground in contained mills leading to aggregate which is separated by riddles/screens of different sizes. Organic material like pieces of wood, soil, etc. (which remained on the concrete from transportation) are separated in uplift-filters. [23]

The decision to recycle poles in plants or on site depends on the access to the site, on the amount of material, and on the possibility to reuse the material in near locations.

The recycled aggregate can be used as additives for concrete, for the construction of streets and lanes, in the housing industry, as backfill for underground cables, as landfill and many others uses.

5.1.4 Foundations

5.1.4.1 Principles

Monoblock foundations (concrete)

Monoblock foundations are reinforced or plain concrete compact foundations which encase all the support legs. These foundations are mainly used for small lattice steel towers, steel and concrete poles. The foundations are normally 0.1 m to 0.5 m above the ground level and do not occupy an excessive area.

Separate Foundations

High voltage overhead transmission lines of 132 kV and above are usually constructed with lattice steel supports with individual separate foundations. Typically the foundations comprise concrete pyramid/pad and chimney foundations, stepped concrete blocks or drilled shaft/augered foundations. The projecting concrete chimney is usually between 0.6 m and 1.5 m (square or circular) and 0.3 to 0.5 m above ground level. The chimneys can be coated for environmental reasons, either to prevent deterioration of the concrete or to reduce the visual impact. Below ground level the depth of the foundations may vary from 2 m to 6 m with a base dimension of between 1.5 m to 5.0 m.

Piled foundations (steel, concrete)

Piled foundations can either comprise a single pile or a group of piles connected at or just below ground level by a reinforced concrete cap. If the pile cap is below ground level a concrete chimney is used to connect the tower leg to the foundation. The cap may vary in size from 2 m to 15 m, with the piles extending from 5 m to 30 m. The piles may be preformed from steel, pre-cast concrete or timber or cast-in-situ with or without permanent steel or concrete sections.

Grillage foundations (wood, steel)

Grillage foundations consist of either steel or timber sections directly embedded in the soil. The tower leg is directly connected to the top of the grillage and in certain cases the bottom of the grillage is encased in concrete to improve the foundation's performance in weak soils.

5.1.4.2 Dismantling and recycling of foundations

Dismantling

The procedure for dismantling and recycling of concrete foundations is similar to concrete poles or steel towers as described before.

When dismantling pad and chimney- foundations, normally the pads remain in the ground and chimneys are removed. When dismantling piles, normally the piles and the caps remain in the ground, and chimneys are removed. When dismantling grillage foundations, often the grillage remains in the ground, and tower legs respective chimneys are removed.

Recycling

Recycling of the various types of foundations is similar to the recycling of supports. The materials are to be separated either on site or in plants. Recycling of foundations is not demanded by law in most countries and is not common practice for utilities.

If lines are dismantled not all the foundations are removed and then not always completely. The depth that foundations remain below the ground surface, varies from country to country, typical values are between 0.5m and 1.5 m. If foundations are recycled this is more often done on site than in plants and depends on the possibility for access to the site and on the amount of mass to be recycled. Removed grillage foundations can be rebuilt and be reused in foundation refurbishment programs if they are in a good condition.

5.1.5 Earthing Systems

5.1.5.1 Materials

Earthing systems for transmission towers are buried metallic materials which are capable of carrying earth fault currents. These systems can reach out several meters from the tower legs and are buried in depth between 30cm and 100cm below the ground surface. This depth depends on the quality of soil, the kind of agriculture and the kind of cultivation (e.g. the increasing size of ploughs demands deeper earthing systems).

Earthing systems can consist of galvanized steel bands, copperweld or copper material, stranded wires from copper, copperweld, galvanized steel or aluminium and, rarely, stainless steel for major 500kV lines. Where touch and step voltages are low, lines without earthing systems exist. If necessary these materials are protected against corrosion by galvanizing or painting. In bad soil conditions supplements e.g. red earth or bentonite clay may be added.

5.1.5.2 Dismantling and recycling of earthing systems

Dismantling

During dismantling of a line, earthing systems are removed in most cases, but not always completely. Depending on the kind of agriculture and the kind of cultivation as well as depending on the demands from landowners and authorities, the systems may stay in the soil below a certain depth. Typical values are below 50 and 100cm.

Recycling

Recycling of earthing system follows the same principles as for lattice towers or metallic poles or conductors of aluminium or copper. 100% can be recycled.

5.1.6 Recycling: Legal Situation

Legal obligations for recycling and for treatment of waste exist in several countries. In Austria for example the law about separation of material from building works (Verordnung über die Trennung von bei Bautätigkeiten anfallenden Materialien) defines thresholds above which such materials are to be separated [24]:

soil	20 tons
concrete	20 tons
tarmac	5 tons
wood	5 tons
metal	2 tons
mineral rubble	40 tons

5.1.7 Conclusions

5.1.7.1 Production

The base material for towers made of steel can consist of a certain amount of scrap material. The procedure for production is standard for steel works. Concrete poles can be moulded or can be produced by centrifugal methods. Wooden poles are made from complete trees or laminated wood.

5.1.7.2 Corrosion protection, preservation

Towers made of steel need protection against corrosion. Galvanising, a paint coating or both (Duplex System) ensure a long lifetime for the structure, in the range from decades up to a hundred years. Modern coatings on a water soluble base without solvents reduce pollution. Any kind of protection material has to be applied permanently to prevent corrosion and to prevent pollution of soil due to abrasion of zinc.

Rusting steel has been used in several countries in the past instead of a protective coating but has not achieved wide acceptance.

Wooden poles need preservation against fungi, parasites and other environmental influences. All preservation materials have some influences on the environment and the soil. They disappear after a certain period of time and must be renewed periodically.

5.1.7.3 Dismantling and Recycling

Material from dismantled metallic structures is considered as raw material with good value.

Dismantled wooden poles can be used for several purposes as paddocks, scaffolds, retaining walls for roads, emergency structures, road barriers, etc. Recycling of concrete poles can reach a very high percentage. In modern plants 100% of concrete and reinforcing steel can be recycled.

Foundations are normally removed to a certain level below the surface, typical values are between 50cm and 100cm. The recycling of foundations follows the same principles as for structures.

Earthing systems are made of steel or copper. Whether they are removed completely or not varies from country to country. If they remain in the soil, typical values are below 50cm and this depends strongly on the kind of agriculture in the area.

5.2 Conductors

5.2.1 ACSR

According to the report "Survey on future use of conductors" produced by SC22 TF12-1 in 1998, conductors in use worldwide on existing overhead transmission lines over 100kV are about 82% aluminum conductor steel reinforced (ACSR), about 6% all aluminum-alloy conductor (AAAC) and about 4% all aluminum conductor (AAC). This data is based on questionnaire responses received from 71 utilities in 13 countries (USA, Canada, Japan, Australia/NZ, UK, Ireland, Scandinavia, others). ACSR is composite type conductor with two different types of metals; aluminum wire and galvanized steel wire. On the other hand, AAAC consists of a single metal stranded wire of aluminum-alloy with increased strength, and AAC consists of a single metal stranded wire of aluminum. This section describes LCA for ACSR only because we consider that LCA for ACSR would cover major aspects of LCA for AAAC and AAC.

Corrosion protection of ACSR should be taken into account according to the contamination area category such as coastal and industrial areas, where the corrosion processes are different, however this corrosion does not seem to have big environmental impacts.

There is a high rate of recycling of dismantled ACSR conductors and cascade recycling is common to reuse them as secondary processed products.

5.2.1.1 Raw material

The main component metals of ACSR are aluminum, iron and zinc as a coating material. The processes to manufacture these metals from ores (bauxite, ironstone, zinc ore) are industrially standardised.

While the recycling rate of aluminum and iron in Japan is very high with about 55% and 40%, the recycling rate of zinc is low with about 15% because zinc is generally added widely in small quantities to other metals as coating materials. The metal recycling system contributes largely not only to resource saving and waste reduction but also to mitigation of environmental impact in the metal manufacturing processes. Especially, the energy required to turn aluminum scraps into secondary ingots is only about 3% in comparison to the amount required to make virgin ingots from bauxite.

However, because the component metals of ACSR requires high quality (mechanical tensile strength, electric characteristics such as conductivity, and so on), secondary ingots such as aluminum and iron made from scraps are usually not recycled as materials for ACSR.

5.2.1.2 Production

ACSR is a concentric-lay-stranded conductor of aluminum wire and galvanized steel wire. Its mechanical tensile strength is mainly provided by the steel wires, and its aluminum wires act as the electric conductor.

The range of nominal cross sectional areas of ACSR commonly used in overhead transmission lines by electric power companies in Japan is now 120-1,520 mm^2. The diameter of the galvanized steel wire is usually 2.3-4.8 mm, and the core of the ACSR consists of seven galvanized stranded steel wires formed by a wire-stranding machine. This galvanized stranded steel wire core and reels of aluminum wires (wire diameter is 2.3-4.8 mm, the same as the steel wire) are put into a wire-stranding machine, and ACSR is manufactured. Layers are stranded concentrically, with successive layers having opposite lay direction. There are no substances or by-products which may affect the environment in this stranding process.

Galvanized steel wire

A high carbon wire rod is put on a reel at ambient temperatures, passed continuously through several kinds of dies, and is drawn to a predetermined diameter. Grease is used in this drawing, which must be removed since it is impossible to galvanize while this grease is on the surface. The grease is carbonized in a lead furnace, cleaned off using hydrochloric acid and wires are then rinsed in water. The drawn and washed wire is put into a melting furnace, and hot dip galvanised. It is cooled with water after coating, and the galvanised steel wire is then completed.

The hydrochloric acid and water used to remove the grease are treated after being neutralized. Since this waste treatment is carried out at a manufacturing facility, the influence to the environment can be minimized.

Aluminum wire

Aluminum wire is manufactured by hot-rolling aluminum metal into a rough drawn wire with a predetermined size or through a continuous casting process. It is then put into a wire drawing machine at ambient temperature, and continuously passed through several dies and drawn to the predetermined diameter.

When a rough drawn wire is processed at ambient temperature, it is hardened because its crystal grain is miniaturised, and its tensile strength increases. On the other hand conductivity will fall and it is necessary to take this into account beforehand in order to ensure the predetermined conductivity.

Although grease is used in the aluminum wire drawing process like that of steel wire, there are no harmful substances that will affect the environment in the aluminum wire manufacturing processes since there is no grease removal process from the aluminum wire surface, and refined aluminum is used.

5.2.1.3 Corrosion protection

Corrosion

Although aluminum is very reactive and oxidises easily, it is practically a corrosive resistant metal. The reason for this corrosive resistance is that a closely packed and hard oxide film (Al_2O_3) , which is insoluble in water, is formed spontaneously on the surface of aluminum, and the base aluminum is protected from future corrosion. In a normal environment, it is not easily corroded.

When a transmission line passes through a so-called corrosive environmental area such as a coastal or industrial area, corrosion of the conductor becomes a maintenance problem.

Corrosion in coastal areas

In general, corrosion of ACSR in coastal areas is contact corrosion of the galvanized steel wire and the aluminum strand. Natural electrode potential in seawater is in the order of Fe, Al and Zn, and if water containing salt accumulates in the gaps between wires, contact corrosion of different types of metal takes place between the zinc layer of the galvanized steel wire and the inner layer aluminum strand. When the zinc, which becomes the anode, is exhausted, the iron base is exposed. After the zinc layer is exhausted, a local battery is formed between the iron base and the aluminum strand. In this process, the steel wire is protected, on the other hand, corrosion of the aluminum strand advances. If this corrosion proceeds quickly, a lot of corrosion products are generated and the inside of the conductor expands and absorbs moisture, promoting further corrosion.

Corrosion in industrial areas

Corrosion of ACSR poses a problem in industrial areas and it is limited to local areas where specific corrosive gas and dusts are concentrated. Soot, dirt, heavy metal powder, etc. adhere to the surface of the aluminum strand outer layer. Corrosive gases in the atmosphere, moisture, etc. are adsorbed to become an electrolyte, which produces pitting corrosion, forming outside corrosion. Caustic soda, hydrochloric acid, etc. are particular problems for aluminum strands with their corrosive gases. With sulphuric acid and nitric acid, there is almost no corrosion problem due to the protection effect of the oxide film formed on the surface of an aluminum strand.

Although there may be contact corrosion between different types of metal because of the intervention of an electrolyte from corrosive gas between contact parts of the galvanized steel conductor and the aluminum strand and between aluminum strands, generally outside corrosion is dominant.

Influence of corroded conductors

Neither conductors corroded in coastal areas nor conductors corroded in industrial areas cause environmental pollution directly. However, corroded conductors may be replaced with new ones when deterioration of conductors' mechanical properties through corrosion is suspected. At this point, corrosion of conductors causes an environmental impact owing to consumption of extra materials for manufacturing of new conductors.

Protective measures

Although a conductor is exposed in a severe environment, such as wind and rain, for many years, it is required to maintain predetermined mechanical and electric performances over the duration of service. When an ACSR is strung in a severe corrosion environment like a coastal or industrial area, the performance may fall off considerably due to corrosion and the life may become extremely short. Suitable anti-corrosive treatment is necessary. Definite measures are adopted to raise the corrosion resistance of ACSR and to prevent contact between different types of metal and the permeation of electrolyte inside a stranded wire which causes corrosion.

Contact prevention between different types of metal

Conductors (ACSR/AN , ACSR/AC) which eliminate the potential difference between different types of metal and raise corrosion resistance may be adopted by replacing the galvanized steel wire of ACSR with aluminum galvanised steel wire or aluminum-clad steel wire. Most of its other characteristics are equivalent to ACSR, and its economic efficiency is high.

Electrolyte permeation prevention

Corrosion resistance can be increased by applying a grease-like anti-corrosion compound in between the strands (between steel core wires and between aluminum wires) of ACSR to fill the gap and prevent moisture and humidity of the electrolyte from permeating into the points of contact of different types of metal. There are three kinds of anti-corrosion ACSR: light anti-corrosion with corrosive protection only for the steel core, medium anti-corrosion ACSR with corrosive protection for all the inner layers and, heavy anti-corrosion ACSR with corrosive protection for outer layer and all the inner layers.

The type of corrosive protection to be adopted is determined by examining the level of the corrosion environment. Heavy anti-corrosion protection may be adopted when the conductor is very close to a coast and seawater sprays directly onto the conductor surface, or when the conductor is close to a chimney which emits corrosive gases (gaseous chlorine, etc.) like a pulp plant, a paper-making plant, etc. However workability during construction is very poor due to the grease on the surface of the conductor.

For AAAC/AAC having no contact with different types of metal, the anti corrosion processing which covers the outer layer with grease is also desirable when used under such a severe corrosion environment.

Anti-corrosion grease must have heat resistance not to flow at high temperature, cold resistance with sufficient viscosity and adhesion at low temperatures, and chemical neutrality, which contributes to a negligible influence on the natural environment in general use.

The anti-corrosion performance of an anti-corrosion conductor using grease is better than that of an aluminium clad steel conductor.

5.2.1.4 Scrapping and recycling

Scrapping

Dismantled ACSR conductors are usually pulled back by winding them around a drum at a construction site. The removed conductors are conveyed to a recycling plant and finely cut into lengths of about 3-5 cm at the plant. At this stage, aluminum wire scraps and steel core wire scraps are randomly mixed. A magnetic conveyor picks out the steel core wire scraps, and the aluminum wire scraps are separated.

Since both the aluminum wire and steel core wire scraps are separated in a recycling plant, influence on the natural environment does not pose a problem.

Both AAAC and AAC are mono-metallic aluminum conductors, so that, unlike ACSR, a separating process is unnecessary and this is considered to be advantageous.

Recycling

Aluminum wire scraps and steel core wire scraps usually have a very high rate of recycling. Not only dismantled conductors but also aluminum wire scraps and steel core wire scraps, which are generated from the manufacturing process, are recycled.

After separating at a recycling plant, it is processed so that aluminum conductor scraps may be recycled as aluminum and steel core wire scraps recycled as steel, to be used as recycled materials.

Generally, removed aluminum wire scraps are not recycled as materials for aluminum conductors. Conductivity, corrosion resistance, etc. require highly pure aluminum for conductors. Impurity removal after re-melting is difficult since aluminum easily combines with other metals, etc. Electro chemical processes, etc. are highly effective in removing impurities, but are not economically efficient and not practical. For this reason, dismantled aluminum wire scraps are popularly processed as a secondary alloy after melting and removing impurities, and used for construction and civil engineering related materials and auto engines. They are further collected after use, and are again processed and reused as a secondary alloy (cascade recycle).

Steel core wire scraps are commonly melted without separating the zinc because of the cost aspect. In addition, grease on anti-corrosion ACSR is not easily separated. Even if the melting process is carried out, the oil ingredient of grease may cause pollution, and it will be the subject of future recycling investigations.

5.2.2 Conclusion

5.2.2.1 Raw material

The processes to manufacture the main component metals of ACSR (aluminum, iron, zinc) from ores (bauxite, ironstone, zinc ore) are industrially standardised.

5.2.2.2 Production

Suitable processing and disposal treatment is carried out on the hydrochloric acid and water produced in manufacturing conductor galvanised steel wires in manufacturing facilities, and this results in a minimal influence of the environment.

5.2.2.3 Corrosion protection

Corroded ACSRs do not cause an environmental pollution problem. Because the grease used to fill the interstices of the conductor is resistant to heat and cold and is chemically neutral, the influence on the natural environment is generally negligible in normal use.

5.2.2.4 Dismantling and recycling

Both the aluminum wire scraps and steel core wire scraps which were produced in dismantling and manufacturing processes for conductors usually have a very high rate of recycling.

A suitable grease treatment method has not been established for recycling anti-corrosion ACSR, and this is a subject for future study.

5.3 Insulators

5.3.1 Introduction

They are three mains type of insulators: toughened glass, porcelain and composite. Overhead line insulators are of the cap and pin type in toughened glass and porcelain and of the long rod type in porcelain and composite materials. They are used in strings or as long rod units, or multiples of them, to insulate the conductors from the structure. Insulator dimensions and functional characteristics are regulated by numerous international and national standards.

5.3.2 Raw Materials

Glass and porcelain insulators

They consist of four separate types of materials:

- glass : toughened for string cap and pin insulators
- porcelain: for string cap and pin insulators and long rod
- assembly materials: aluminous cement mortar or portland cement
- metal cap and pins or end fittings: most often made of ferrous metal (galvanized malleable or ductile iron and steel) with zinc alloy ring on pins for better corrosion performance.

Composite insulators

These consist basically of three different kinds of materials:

- rods of resin bonded fiberglass reinforced
- housing materials: most often made of Ethylene-Propylene Diene Monomer (EPDM) rubber and silicone rubber or a mixture of the two.
- metal end fittings made of galvanized malleable or ductile iron and steel or aluminum alloys.

5.3.3 Corrosion Protection

The metal caps and pins and end fittings are subjected to corrosion caused by chemical or electrochemical processes, e.g. in the presence of oxygen and water as well as through attacks by aggressive media, such as SO_2 under conditions of high humidity, which result in the formation of sulphuric acid (H_2SO_4) and consequently destroys the metallic surface.

All ferrous parts need protection against corrosion. The corrosion protection used is a galvanisation coating which acts as a reactive anode.

5.3.4 Recycling of Insulators

5.3.4.1 Glass recycling

To be recycled, glass must be crushed and pollution free. For toughened glass, the crushing stage is eliminated since toughened glass may be broken by mechanical shock.

The major difficulty resides in separating the glass from the aluminous cement, a refractory cement which is detrimental to fusion and is a source of inclusions. The cement ratio in relation to the overall glass cement content ranges from 4 to 7% depending on the type of insulator involved.

Given the very high noxiousness of inclusions in the glass to be used for insulators, it would seem that recycled glass could only be used, once the cement fragments have been removed, to manufacture objects which are of a lesser quality than the insulators, for example bottles.

In case of toughened glass insulators recyclable and reclaimable products represent, in terms of weight, more than 90% of the volume of collected products.

5.3.4.2 Porcelain recycling

Porcelain material cannot be recycled directly into the manufacturing process as in the case of glass. The porcelain from discarded insulators can be broken into pieces and discarded in landfills. It can also be ground and used in concrete and polymer concrete materials. An example of recycling porcelain from insulators is to produce concrete blocks used in the pavement of streets and sidewalks.

5.3.4.3 Composite recycling

Polymer housing

The polymer housing of the composite insulators can be recycled at several levels.

Primary recycling means the use of in-house scrap for purposes identical with that of the original raw material. This can be easily performed for thermoplastics, but not for thermosets including rubber.

Secondary recycling is the collection and re-processing of polymer scraps. This process involves the selective collection, cleaning, de-vulcanization and re-granulation of polymeric waste. In the case of rubbers a secondary recycling is limited to milling and/or partial de-vulcanization, in which plastic waste is used to produce monomeric or oligomeric products, which can be used for the synthesis of new polymers or other chemicals. Reclaimed rubber is an intermediate step between mechanical comminuting and depolymerization, as the network of the reclaimed rubber particles is partially destroyed but does not reach the monomeric or oligomeric level. Thermal cracking of polyolefins (e.g. EPDM) is also a viable alternative, which results in a series of products similar to those of paraffin cracking used in the petro-chemical industry.

Tertiary recycling has certain advantages over the secondary one. The products of tertiary recycling can be well purified and used as any other chemical obtained from petro-chemical industries. It means that the product obtained from tertiary recycling is in all respects identical with the virgin one, while in the case of secondary recycling the recycled product is of necessity inferior as compared to the new one. Raw materials obtained from tertiary recycling are, of course, usually more expensive than the monomers produced by the petro-chemical industry, which means that the cost of recycling must be incorporated into the production cost. This means the increase of price or the reduction of profit, so it is not readily accepted without the help of state legislation.

Quaternary recycling covers all other end-uses from burning to landfill or others. In some cases the gaseous fuel obtained from plastic pyrolysis is also burnt instead of being used as synthesis gas. This is the most adequate processing method of plastic waste co-mingled with other municipal waste. In several cases this is the only viable technology for contaminated plastic waste, even if it is selectively collected.

Silicone rubber housing

In the case of silicone rubbers both secondary and tertiary recycling techniques are, in principle, available. Rubbers can be milled into fine powders both at room temperature and at cryogenic temperatures. Cryogenic technology results in finer and smoother rubber particles. As the glass transition temperature of silicone rubber is $-120\ ^{o}C$, liquid nitrogen is needed for cryogrinding, which makes the technology expensive. A partial de-vulcanization by steam is also possible, which results in rubber “reclaim”. High temperature treatment (pyrolysis) transforms pure silicone rubbers into a mixture of cyclic siloxanes that, after cleaning and separation, can be used for silicone rubber synthesis. The problem with this approach is that the presence of fillers (especially active fillers) changes drastically the yield of volatile organic siloxanes and a lot of solid waste is produced.

Fiberglass reinforced epoxy rods

The fiberglass rods are not recycled. They are cut into pieces and used as back fill.

5.3.4.4 Recycling of ferrous metal

Recycling of ferrous metal is common practice with a very high percentage reclaimed. The material is considered as raw material with good value.

5.3.5 Conclusions

5.3.5.1 Production

The base material for insulators (glass, porcelain, polymer housing) is generally made from basic raw materials. Only for the metal fittings can a certain amount of scrap material be used.

5.3.5.2 Corrosion protection

All metal parts need protection against corrosion (galvanisation coating).

5.3.5.3 Dismantling and recycling

Material from metallic pieces is considered as raw material with good value. 100% of it can be used.

Glass recycling can be used for low quality glass such as bottles, but most of the time it is used, as is recycled porcelain, for backfill.

The polymer housing of the composite insulator is very difficult and expensive to recycle. This cost is higher than the one produced from the petro-chemical industry.

6. LIFE CYCLE ASSESSMENT, OVERVIEW FOR CONSTRUCTION AND MAINTENANCE

6.1 Construction

6.1.1 General

The construction phase of a line has some of the most significant influences on the environment over the life of an overhead line (apart from losses during operation). The reason is the transport of material to the sites, the clearing of the right of way (ROW) and the work itself. Access roads will become necessary or the material is transported by helicopters. Also ropeways may be a solution in mountainous regions.

6.1.2 Clearing of the right-of-way (ROW)

The ROW must be cleared in such a way that the electrical clearances and fire risk clearances from trees and bushes are kept e.g. where the crossing of forests is not foreseen. The cutting of trees is often done by the landowners themselves or is carried out by contractors. The treatment and shape of the ROW after finalisation of the erection works is an important issue and is defined precisely during the relevant authorization procedures.

6.1.3 Foundation work

The opening of the pits for the foundations needs excavators and other machines which depend on the size of the foundation and the amount of soil which is to be moved. Machines for piles often run on caterpillar tracks to reduce the pressure on soil and prevent damage. Concrete is normally provided pre-mixed and transported to site. Reinforcing steel is brought on site either as members or pre-assembled.

6.1.4 Erection of towers

Members of lattice towers are brought on site and can be pre-assembled before erection. They are lifted and mounted by use of mobile cranes or other assembling aids, such as gin poles or derricks. At locations with poor access, the use of helicopters is common. Metallic poles and concrete poles are transported in sections and are often brought in assembled by helicopters.

6.1.5 Stringing work

Stringing work needs access for the delivery of conductor drums, pullers, brakes (tensioners) and other machines. This machinery needs considerable space and normally cannot be transported by helicopters due to its heavy weight. If the terrain allows, the stringing is done over sections of some kilometres. Places for material and stringing machinery are therefore needed kilometres apart.

If the pulling ropes are brought out manually a small corridor of few meters along the axis of the line is necessary in cases the ROW is not free of vegetation (e.g. crossing of forests or bushes). Scaffolds protect obstacles from the pulling rope and from the conductors during the stringing works. This small corridor is abandoned after completion of the erection works.

6.2 Maintenance

6.2.1 General

Maintenance means all efforts required to keep the line in such a condition that it fulfils its given tasks in accordance with the prescriptions from laws, regulations and from the authorisation and to ensure safety and security. It must also perform within the design parameters of the line with respect to line faults originating from biotic aspects such as plants and animals (e.g. fires and birds) The line's components therefore need to be checked periodically. This inspection covers conductors and earth wires, fittings, insulators, structures, foundations, earthing systems, clearances (especially to trees within the ROW).The condition of any erosion that may threaten the towers or access roads must also be recorded during this inspection.

Inspection intervals depend on the following considerations:

- climatic conditions (e.g. aggressive atmosphere or not, danger of avalanches, stress on material from additional loads, frequency of lightning strokes)
- topography (e.g. danger of landslides, earthing conditions, erosion)
- type and quality of components (e.g. surface treatment of structures, type of conductors, quality of concrete for foundation)
- age of the line and its components (e.g. expected lifetime)
- vegetation along the ROW (e.g. periodic cutting of branches or trees or the condition of annual grasses which could fuel fires)
- probability of vandalism (e.g. dismantling of members of structures)
- experience and estimation of the utility with regard to all these aspects (e.g. vibrations to be expected or not)

The measures to be taken for maintenance depend on the results of the inspection. It may be necessary to implement them immediately or they may be done together as planned maintenance. Special aspects are faults or accidents which need immediate responses (e.g. collisions of cars with towers or aircraft with conductors, avalanches). The work required to replace components is similar to that for new installations.

Interactions between birds and overhead lines may exist and can consist of:

1. Nesting
2. Bird pollutions (streamer) related faults
3. Collisions of large birds with conductors or earth wires

The remedies for the above problems are:

1. The relocation of nests on the same structure, under supervision of an ornithologist, where the nest proves to be a problem.
2. The fitting of bird guards on those towers identified with a problem
3. The fitting of anti-collision devices in areas identified as high collision risk areas

Fires can be a cause for fire faults on overhead lines, especially in countries where a high number of fires occur in grass and savanna areas or where sugar cane is grown. These plants grow annually and have to be inspected at the end of the growing season and remedies implemented before the onset of the winter fire season starts. (This situation may vary from one country to another). In certain cases invader shrubs could pose a fire risk and these plants are reduced by mechanical, chemical (herbicides) or biological means. An example of biological control would be the introduction of insects that feed on the seeds of the invader plants. These measures are however, carefully studied before implementation. Fire is also used as a means of reducing plant fuels and these controlled burns are executed at night in order to reduce the risk of flashover during the burn.

Inspections carried out by helicopter should carefully consider the existence of game areas. Animals like elephants are often captured using helicopters. The noise of the helicopter that carries out a power line inspection may cause the elephants to stampede. Other animals like ostriches and antelopes are also frightened by helicopters and have killed themselves on fences in an effort to get away from the helicopter. Cases have been reported where large raptors have attacked the helicopter in order to protect their nest.

Care should therefore be exercised when using helicopters for inspection where these animals occur respective similar considerations shall be taken under comparable conditions.

Erosion can affect the overhead line in the following three ways:

1. Erosion that threatens the tower
2. Erosion that threatens the access road
3. The causing of erosion may be a legal environmental contravention or contrary to company policy.

Several measures exist to prevent erosion or for repairing erosion if it has already occurred, [25], [26].

6.2.2 Access for inspection

Inspection is mostly done visually either from the ground or from helicopters. If from the ground, small groups of linesmen need access to the towers and along the route. They climb the towers and can check all components of the line with the exception of a detailed check of the conductors in the spans. In sensitive areas access roads can be prevented.

The right-of-way is often used to carry out inspections of line components. These inspections are mainly performed using

for ground-level inspections

- Trucks (summer)
- ATVs (summer)
- Tracked vehicles (summer, winter)
- Snowmobiles (winter)

for aerial inspections

- Helicopter (summer, winter)
- light aircraft

During ground inspections performed in the summer, some rivers may be forded where there are no bridges, culverts or bypass roads. In some utilities, an in-house policy can set out the rules to be followed regarding fording. Inspection from helicopters can be done visually or they may use modern stabilised infrared systems to estimate the condition of conductors and fittings. In some regions (e.g. dense forests) the use of a helicopter requires that right-of-ways be cleared over a wider area so that the aircraft can land. Maintenance programs must therefore take this aspect into account when setting vegetation tolerance requirements.

6.2.2.1 Vegetation control in right-of-ways and access roads

Vegetation in the right –of-way impacts the overhead line in the following three ways:

1. Plants may compromise electrical clearances
2. Large trees may fall on conductors or towers
3. Plants may provide fuel for fires. This includes grass, shrubs and trees.

Vegetation in rights of way and access roads is controlled using the concept of integrated vegetation management (IVM), which consists of using the right type of method (mechanical or chemical) at the right location and at the right time. Based on the site and type of work being done, the return cycle can range from 4 to 15 years. In some countries the design and shape of the corridors, kind of plants, etc. is given.

A modern concept is the use of aerial photographs. Generally, one year before the year when the vegetation work is to be done, low-altitude colour aerial photographs are taken of the right-of-ways (approximate scale: 1:500 to 1:2000).

The photo-interpretation of the images is then used to:

- Identify sensitive elements
- Delineate buffer zones for the sensitive elements;
- Identify the type of vegetation present (type, height, density and sociability)
- Identify the type of work that needs to be done
- Identify specific environmental elements

Field validations and an environmental assessment are then undertaken to supplement the information.

The main types of work are:

- Mechanical cutting equipment (manual or motorised) in most of the surface areas
- Herbicides (ground spraying, aerial spraying, stump cutting and treatment) is the practice in some countries for the minor part of the surface areas but is not allowed in other countries.

Vegetation management should also consider the possible effects on erosion. Depending on the work being done, the main types of vehicles used for vegetation control consist of ATVs, tracked vehicles, (muskegs), Argo-type vehicles, etc. In the case of annual plants (shrubs and grass species) more rapid methods must be employed. Early work on the use of helicopter born hyperspectral methods are being researched. In one case aerial spraying of weeds was carried out by micro-light aircraft.

6.2.3 Access for maintenance works

For some maintenance works material needs to be transported to site. Access roads will become necessary or the material has to be transported by helicopters. Also ropeways are the practice in some regions. Emergency work and major repairs often involves the use of heavy land-based machinery. To limit the impact, temporary bridges or culverts can be built. Once the work has been completed, the land can then restored to its initial state.

Emergency work and major repairs often involves the use of heavy land-based machinery. To limit the impact, temporary bridges or culverts can be built. Once the work has been completed, the land is then restored to its initial state.

6.2.4 Maintenance works

Properly built lines should not require much maintenance work. During the initial years maintenance work will concentrate on the cutting of trees within the ROW to preserve the clearances. Other maintenance work will become necessary years or even decades after erection and will mainly concentrate on surface treatment of the structures.

6.2.4.1 Maintenance painting

A survey among members of WG 15 showed that 80% of the utilities which replied paint steel towers. The frequency of painting is between every 15 and 25 years. Duplex-in-factory coated structures need painting every 35 to 45 years. The expected lifetime of steel towers was indicated as between 40 and 100 years. This means that painting of steel towers is the measure with the highest frequency of all maintenance works. During maintenance painting access to the towers is needed, but not with heavy machinery. To protect agricultural land from dust and painting material, protection measures are often taken in such cases.

6.2.4.2 Replacement of Insulators, fittings and conductors

A survey among members of WG 15 showed that the lifetime of insulators is estimated as between 35 and 70 years. The same may be supposed for fittings. The replacement of these components needs access for light trucks to the towers.

6.2.4.3 Replacement of conductors and earth wires

The lifetime of conductors and earthwires may be estimated to be approximately 60 years (ACSR, AAAC, and similar) provided vibrations or other destructive phenomena do not occur or are suppressed. The efforts for these works are similar as those for stringing during erection of a line.

6.2.4.4 Emergency work and major repairs

These works are necessary e.g. after accidents and very often must be carried out in a short time span. The efforts depend on the kind of work and can be similar to those for erection of new towers or stringing works.

6.2.5 Restoration of the right-of-way after the line has been dismantled (surrender)

When a transmission line is no longer needed, it can be dismantled and the right-of-way surrendered to the private landowner or to the government in the case of forests on public land. The dismantling work requires the utility to carry out an environmental impact assessment (EIA) and develop a management plan for this purpose. The "Polluter Pay" principle will apply here. The ROW should be restored to the original condition or to a condition which is given by the authority. It is however more feasible to "re-cycle" the ROW and use it for an upgrade, if possible. The dismantling work requires the use of heavy machinery which may cause damage to the environment. To limit these impacts, temporary bridges or culverts are built when required and the right-of-way is restored to its initial state once the work has been completed.

Additional work may be required, such as ensuring that the soil has not been contaminated, implementing forest management measures, etc. Before a line is dismantled, an environmental assessment must first be done in some countries.

6.3 Access Roads

6.3.1 Types of access roads

Access roads may produce a certain impact on the environment. Two categories may be distinguished: temporary and permanent roads. Temporary roads are required during the construction as well as during the maintenance phase of the life cycle of the servitude. The impact during construction is probably the most severe. Where they are not required after construction, they have to be dismantled after the finalisation of the work and are rebuilt. In cases where these temporary roads will be required for maintenance and inspection, care should be taken to prevent erosion They sometimes consist of special roadways using synthetic material in case they traverse sensitive terrain, such as rivers or areas with easily eroded soils.. Permanent roads remain after the finalisation of the work for maintenance purposes or they may become agricultural or forestry roads. Whether roads shall be removed or not depends on the agreement with landowners and on legal prescriptions. Roads or tracks parallel to the line are not always necessary and are an exception in some countries. The access to towers depends on the terrain, climate and the existing grid of roads as well as on the machinery and methods for maintenance. The use of helicopters can reduce the need for roads. In some cases paths are sufficient for maintenance, in others cases even paths are not necessary. Impacts can be reduced by coordination with landowners or land or forestry agencies to use existing roads and tracks for construction and maintenance purposes. In some cases access roads may have the function of fire corridors (similar to ROW).

6.3.2 Legal procedures for access roads

In general legal and environmental procedures for new access roads are required and covered during the EIA and negotiations. Existing roads should be used whenever possible. In the latter case special arrangements may have to be made with the land owner, if these roads are not public roads normally. Roads in forests or natural parks demand separate investigations.

6.3.3 Dismantling and recycling of access roads

The material used for access roads is standard material for road works such as aggregate, sand and stones. In general no tarmac is applied. All these substances can be dismantled easily and can either be reused for other similar projects or can be recycled. After dismantling and re-cultivation no influences remain on the soil. In very sensitive regions synthetic material for access tracks can be used to reduce the pressure on sensitive surfaces. This material can be stored and reused for similar actions. If recycled, this shall be carried out in special plants taking into account the properties of the material.

6.4 Soil Protection

6.4.1 Objectives

The following statements are from Swiss sources [27] and are given as an example of best practice.

Objective 1: Soils should not be irreversibly damaged by any human activity; this means that they are to be used in a sustainable manner. This is an urgent requirement, because future generations have a justifiable right to soils, which are fertile, and can be used in a manner appropriate to their location.

In specific terms, this means for example that:

- Soils should no longer become polluted by contaminants, which may accumulate there.
- Soil erosion should not exceed the rate of new soil formation.
- No living organisms or toxins foreign to soil should be allowed to enter the soil if they might permanently damage its flora and fauna and thus endanger its ability to function.

Objective 2: Soil protection should be accepted as a commitment of our society. Protection of watercourses, air or forests is nowadays accepted without question. This acceptance does not yet encompass soils, even though it is indisputable that human life is inconceivable without soil. Authorities, researchers and educators should recognize soil protection as not being less important a commitment and should create or expand the necessary framework in terms of institutions and human and financial resources. The subject “Soil” should be included in school curricula. Age-appropriate teaching materials should be provided.

Objective 3: Soils should be protected in advance against detrimental impacts. Only preventive soil protection can stop irreversible damage from happening. It is also the cheapest method of soil protection, for remedial work is very costly (where it is possible at all). Threats to the soil should be neutralized at an early stage.

Preventive soil protection means are, for example:

- Producing, approving, selling and using only substances, organisms, appliances, machinery and vehicles that, when used properly, do not cause permanent harm to the soil.
- Ensuring through education and information that the soil is treated with care.
- Taking the concerns of soil protection into account in air pollution control, waste management or water pollution prevention.

Objective 4: The open land should be preserved in terms of total area. Effective town and country planning measures should be employed to prevent the continued sealing of soil with no substitute being provided. For example, new sealing should wherever possible be compensated for by removing existing installations and restoring an area that can be cultivated. What applies to the forest should also apply to the soil. This is the only way to achieve economical land use.

6.4.2 Soil protection by law and by agreement

Demands for soil protection during construction are manifold and are mainly concentrated on ecological and geological aspects. Typical examples are: ecological and geological site control during construction work, consideration in EIA procedures, avoidance of sensitive areas identified during the EIA study or others, laws for soil contamination and decontamination, prevention of erosion, management of acid sulphate soils to prevent contamination of other soil and water courses, impacts on water quality, and others.

Legal requirements for the restoration of soil after dismantling of towers are not established in every country. If they are established they can cover de-compaction, re-profiling, re-seeding, soil remedial works, decontamination of contaminated sites consistent with the local environment.

Legal requirements about protection of soil against corrosion protection materials including such works on site) exist in many countries. These requirements cover aspects of galvanising, coating materials, hazardous materials and chemicals. Covering of towers during corrosion protection work on site is generally not common practice, but is usual in some utilities. Legal requirements about pollution of soil by heavy metals exist in many countries although such laws do not necessarily refer to overhead lines.

Agreements between utilities and landowners respective farmers unions regarding measures that should be taken to protect the soil during construction and restoration measures can become practice.

The establishment of legal requirements for the monitoring of dismantled lines and towers has not introduced in general and is an exception.

6.4.3 Soil protection

The following paragraphs present the situation in Switzerland [27] to provide an example of soil protection measures.

Switzerland possesses a basic framework for comprehensive soil protection with the amendments to the Federal Law relating to the Protection of the Environment (USG) which was passed by Parliament in December 1995, and the Federal Law of 1979 relating to Town and Country Planning (RPG).

6.4.3.1 Introduction

Soil protection is a relatively new segment of environmental protection legislation. Until the mid 1980s qualitative soil protection was still virtually unknown. Soil was merely a commodity to be traded and used. For this reason, the availability of data on the function, use and contamination of the soil is patchy. In particular, there is a lack of data collected over a period of several years – so-called “time-series.” Comprehensive inventories exist for some land use characteristics. In Switzerland studies of the element budgets of soils have been made at the regional level; at the national level, fluxes have been analysed for certain substances such as cadmium, mercury or copper.

Since the summer of 1996, a cartographic survey of the present state of Switzerland’s soils has been available for the first time. Fifteen important kinds of impact on soils were quantified with the aid of federal and cantonal experts and evaluated in terms of perceived trends. For assessing the agricultural suitability of soils, there is a comprehensive series of soil suitability maps on a scale of 1: 200,000 as well as soil maps on various smaller scales at regional or local level.

The measurement of the concentrations of eight heavy metals (lead, cadmium, chromium, cobalt, copper, nickel, mercury and zinc) and fluorine by the National Soil Monitoring Network (NABO) covers just a small proportion of soil contaminants.

Further data on concentrations of harmful substances in Switzerland’s soils is available from studies by several cantons and the completed National Research Programme “Nutzung des Bodens in der Schweiz” (Land use in Switzerland) and from projects undertaken by the federal research institutions, departments of the Federal Institutes of Technology in Zurich and Lausanne and the universities. [28]

The sources of the contaminants and the pathways by which they enter the soil are, by and large, known. Several studies provide information on the contaminant content of materials such as wood ash, inorganic fertilizer, farmyard manure or sewage sludge which may enter the soil and contaminate it. Data on physical impacts on soils (compaction, erosion) is mainly available at the regional and local level. A nation-wide survey of the threat to Swiss arable land from compaction was produced as part of the National Research Programme “Soil”.

6.4.3.2 Man-made impacts on soil

Soil, the natural foundation for human, animal and plant life, is subject to quantitative and qualitative impacts. Quantitative impacts are those that reduce the area covered by soils, for example buildings and installations, or that reduce soil depth, for example sealing or soil shrinkage. Soil quality can be impaired by environmentally harmful substances and wastes as well as by compaction and erosion.

6.4.3.3 Contamination

Inorganic substances: The National Soil Monitoring Network, NABO, measures the background “contamination” of soils at 105 sites nation-wide and monitors the changes. It is also responsible for early detection and forecasts of potential soil contamination. The Cantons of Switzerland study particularly contaminated objects, such as industrial sites. In terms of substances, the monitoring of soil contamination in Switzerland has hitherto been limited to the heavy metals and fluorine named in the Ordinance relating to Contaminants in Soil (VSBo) of 9 June 1986, for which there are guide values.

Organic contaminants: Studies of concentrations of organic substances in Swiss soils are few and far between. Examples of these organic contaminants are polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dioxins, phenols and benzenes. These substances are not yet measured by the NABO, and guide values for their concentrations in soil have not yet been defined in Switzerland. However, PAHs and PCBs will be monitored by the NABO in future.

6.4.3.4 Compaction

Driving of heavy construction, sowing or harvesting machinery over the soil can result in compaction. This causes a reduction in pore space and consequently a loss of soil structure. Compacted soils cannot store as much water. Instead of infiltrating, rainfall runs off and promotes erosion and flooding. The decomposition processes in the soil are inhibited because of a lack of oxygen, and root growth is severely impaired (reduced plant yield). Practically all parts of Switzerland with intensive agriculture are at risk from compaction.

Soil protection guidelines are currently in effect which apply especially to the construction of high-pressure natural gas pipelines. The handbook “Bodenschutz beim Bauen” (Soil protection in the construction sector) gives advice to building authorities and the building trade. [29]

6.4.3.5 Erosion

Soil erosion means the surface transport of soil material by wind and water. Whereas water erosion occurs only on sloping land, wind erosion mainly affects level surfaces. Erosion implies loss of organic matter and fine earth, which may entail a loss of productivity. The nutrient- and contaminant-rich eroded material also has the undesirable effect of fertilizing watercourses or valuable biotopes (for instance, oligotrophic sites). Damage to soils by erosion usually occurs gradually and therefore often inconspicuously over years or even decades. The rate of erosion is generally less than two tonnes per hectare per year. In cases of very heavy rainfall, however, it may reach as much as 50 tons. Up to 40 percent of Switzerland’s arable land is affected by erosion. Soils on steep slopes, which do not have a stable turf, also suffer erosion (for instance on ski runs). In general, the rate of erosion exceeds the rate of soil formation. No more than 0.2–1 ton of new soil is formed per hectare per year.

6.4.3.6 Natural contamination

Not all the inorganic contaminants in the soil are anthropogenic; they are also naturally present in the soil in varying concentrations. These contaminants originate from soil-forming rocks. Because of the complex geological conditions, wide regional and especially local variations in the geogenic background, concentrations of heavy metals and fluorine are typical of Switzerland. For the heavy metals chromium, cobalt, lead, nickel, zinc, cadmium and copper, the natural concentrations in the topsoil amount to between 15 and 110 percent of the guide values in the Ordinance relating to Contaminants in Soil (VSBo). For fluorine, natural concentrations range from 100 to 250 percent of the VSBo guide value.

6.4.3.7 Sources of contaminant inputs into soil

Contaminants are predominantly introduced into soils via the two main pathways "agricultural materials" and "airborne inputs." "Agricultural materials" is a generic term for all kinds of fertilizers, including compost and sewage sludge, and plant treatment products. Other sources of contamination are industry, road traffic and other emitters. Whereas the agricultural inputs enter the soil directly, airborne inputs are mainly diffuse.

6.5 Conclusions

6.5.1 Construction

The construction phase of an overhead line can have significant impacts on the environment and these can be the major ones during the lifetime of an overhead line in some impact categories (apart from losses during operation). Access roads and the right of way need to be cleared, material is transported on site, and building machines are working. All these measures come to an end after commissioning of the line, the land can be restored as required by the authorities or by landowners. It is in the interest of the utilities to keep the time for erection short.

6.5.2 Maintenance

Maintenance means all the operations necessary to keep the line in such a condition that it fulfils its given tasks. Periodic inspections of the line's components are therefore necessary. This includes conductors and earth wires, fittings, insulators, structure, foundation, earthing systems, and clearances. Repair work or replacement of components depends on their estimated lifetime which is usually decades. If structures are painted for corrosion protection, maintenance painting becomes necessary every 15 to 25 years and in case of Duplex coating every 35 to 45 years. This means that painting of steel towers is the maintenance measure with the highest frequency of all maintenance works after vegetation management and inspections. The work required to replace components is similiar to that for new installations.

6.5.3 Access roads

Access roads can be temporary or permanent this depends on the agreement with landowners and on legal prescriptions. In some cases access roads may have a secondary function (e.g. as fire corridors).

6.5.4 Soil protection

The protection of soil has a high value in most countries. In others, the following is demanded: no irreversible damage by any human activity, protection of watercourses, air and forests, prevention of continued sealing, decontamination, re-seeding, prevention of erosion, no compaction. This all can be guaranteed by a cautious and responsible design and construction of transmission lines.

7. LIFE CYCLE ASSESSMENT STUDIES - OVERHEAD LINE COMPONENTS

7.1 Life Cycle Assessment (LCA) Studies Methodology

7.1.1 Introduction

Specific calculations of LCA were performed for several limited processes for OHL components (lattice tower, conductor (ACSR), insulator) based on the procedure specified in the ISO 14040 series. An actual analysis is carried out using the LCA software "JEMAI-LCA" which was developed by the Japan Environmental Management Association for Industry (JEMAI). This chapter covers the LCA for the components manufactured in Japan, taking the effects of material and fuel import from abroad into consideration.

7.1.2 LCA phases (ISO 14040)

An analysis is carried out based on the following three basic phases.

- Definition of goal and scope
- Inventory analysis
- Impact assessment

Results of Inventory analysis and Impact assessment are described in subsections for each component.

7.1.3 Definition of goal and scope

7.1.3.1 Goal of the study

This LCA is performed to:

- Make trial calculations of various environmental burdens on the life cycle of each component and roughly assess the environmental impact of them. The results of the assessment may contribute to the future examination on how to develop an appropriate LCA method for OHLs.

The intended audience is as follows:

- CIGRE SCB2 members
- General consumers (customers of electric power companies)
- People in the communities of construction sites for OHLs

7.1.3.2 Function and functional unit

The function of overhead transmission lines in the execution of this LCA is to transmit electricity, and it seems to be appropriate to use electric current unit (A) as the functional unit. However, in the consideration of each unit process for manufacturing the components, the product unit of the components, such as (m) for ACSR, should be used as the functional unit. For the future study, it is necessary to determine the relationship between the number of the components studied and the transmission capacity in a certain model, so that we can convert the results (from (component) to (A)) at the impact assessment phase or other phases.

In this case study, functional units for the each component are as follows.

Component	Functional unit
Lattice tower	1 tower for 154kV line
Conductor	1m (ACSR410mm2)
Insulator	5 pieces of porcelain disc insulator

7.1.3.3 System boundaries

The processes, which will be studied in this study, are shown within the broken line below:

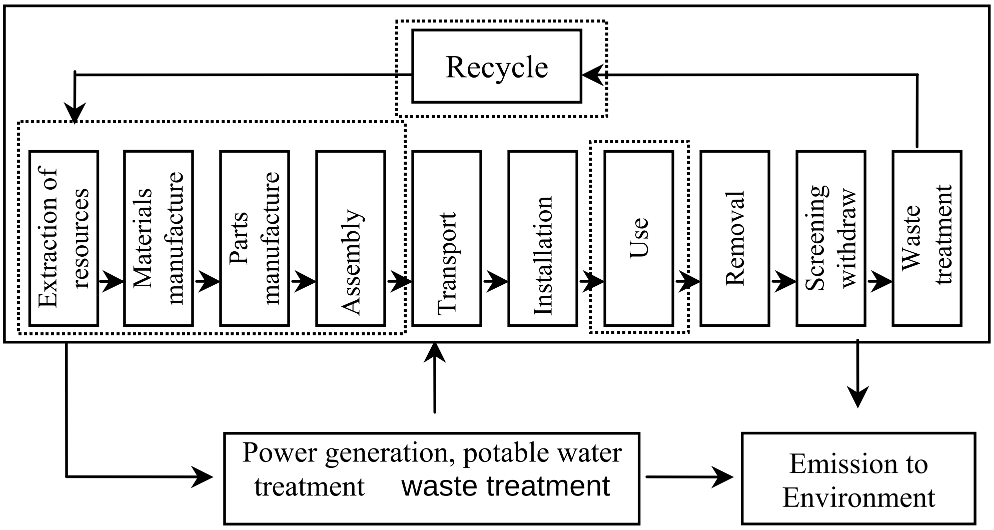


Figure 14: The processes studied in this assessment, shown by

Ideally all of the small processes related to a transmission line should be included within the system boundaries; however from a practical point of view it is not realistic to cover all the processes. A sensitivity analysis approach could be adopted to set the adequate cut-off point. In these case studies, several components (accessories such as compression sleeves, tension clamps, connecting hardware, etc.) are excluded.

Recycling processes are considered in LCA for lattice tower and conductor. On both of the two studies, it is presumed that 90% of the components are recycled except to the foundation of the tower. “Use process” is considered in LCA for conductor as a form of transmission energy loss.

For the details of the processes, please see ***Figures 15 to17.***

7.1.3.4 Data categories

The following data are input or output in the above processes:

- Input of energy and raw materials
- Products (main product, intermediate products, coproducts)
- Emission
  - Emission to air (CO_2, NO_x, SO_x, etc.)
  - Emission to land (solid wastes, etc.)

7.1.4 Methodology for inventory analysis

7.1.4.1 Analysis method

“Process analysis” is applied to the inventory analysis.

7.1.4.2 Applicable system category

In drawing up a process chart to execute LCA, various secondary flows are produced along with a main flow. The following are the basic flows to be considered:

[Secondary flows and how to deal with them]

- ”Capital goods” of factories, power plants and other facilities --- not included in principle.
- The processes of “coproducts” --- when there is a coproduct that may generate economic value profits and is not simply disposed as a waste, the environmental burden in the manufacturing process is divided proportionally between it and the main product.
- “Packing materials” used for transportation --- packing materials are not included in the system except to the wooden dram for ACSR and wooden container for insulators. (Since other packing materials are not so voluminous that the influence of them could be negligible.)
- The manufacturing process of “secondary raw materials” with a small component ratio (not included in principle).
- Human labour (not included in principle).

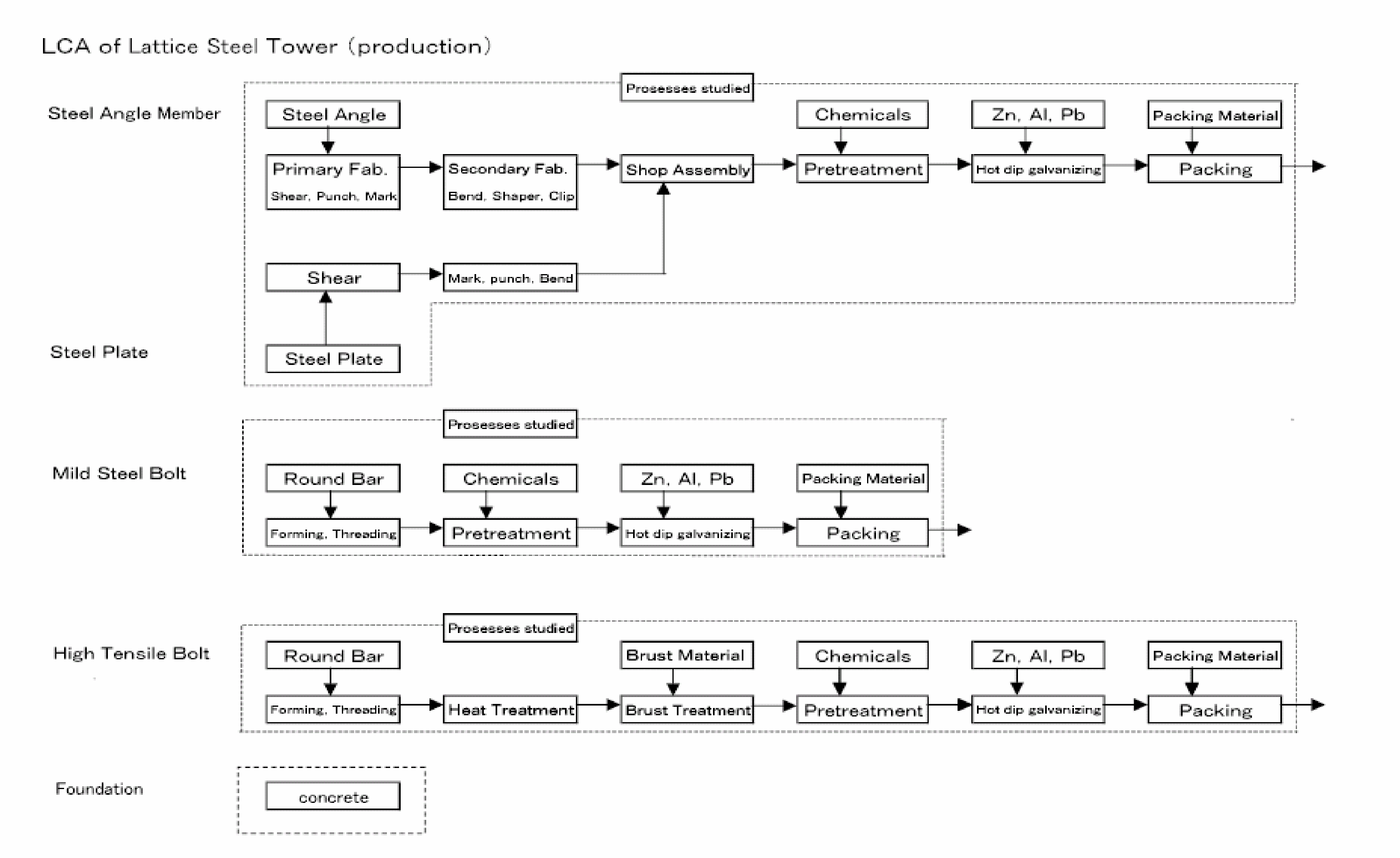


Figure 15: LCA of Lattice Steel Tower (production)

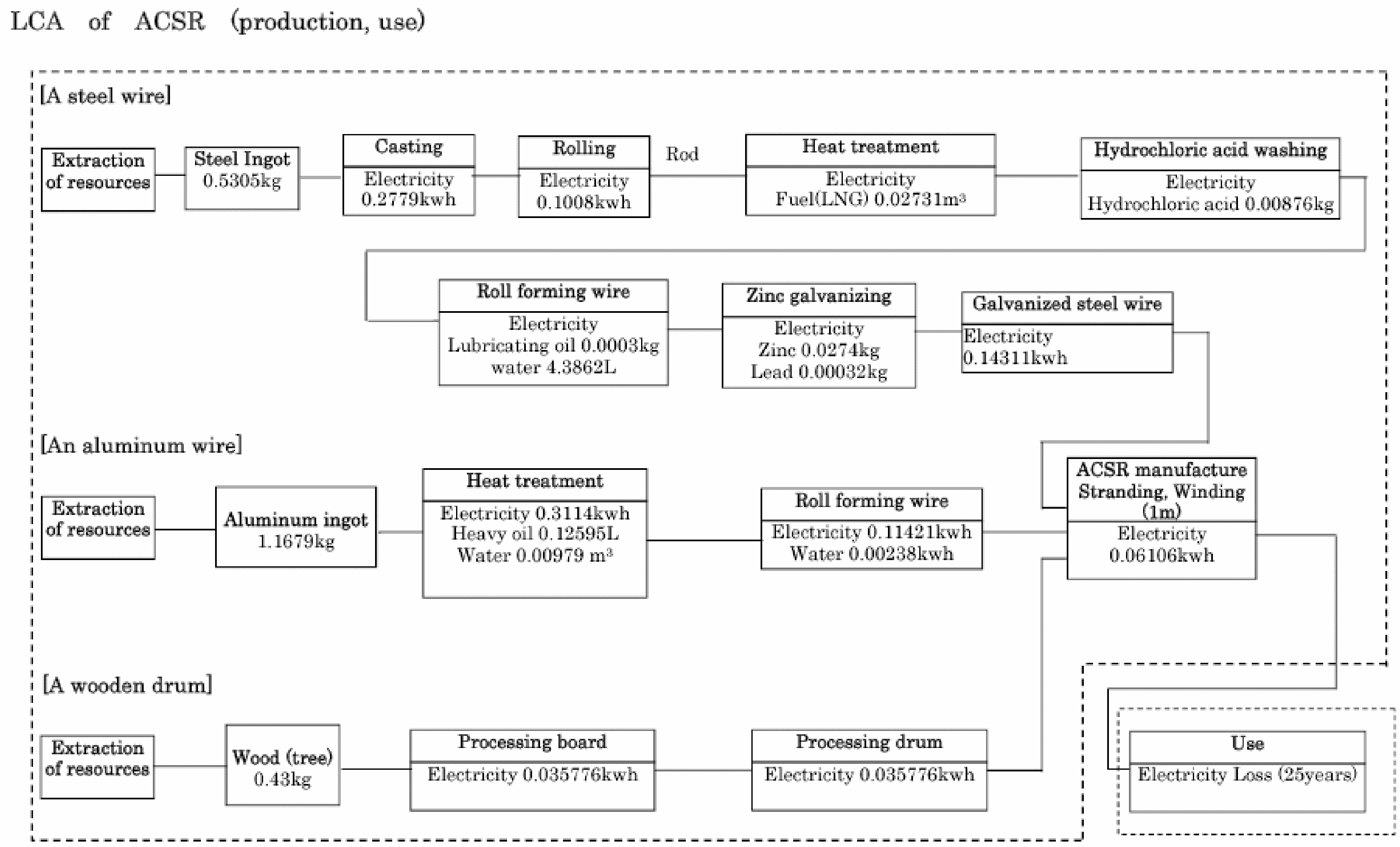


Figure 16: LCA of ACSR (production, use)

LCA of Insulator (Porcelain Disc)

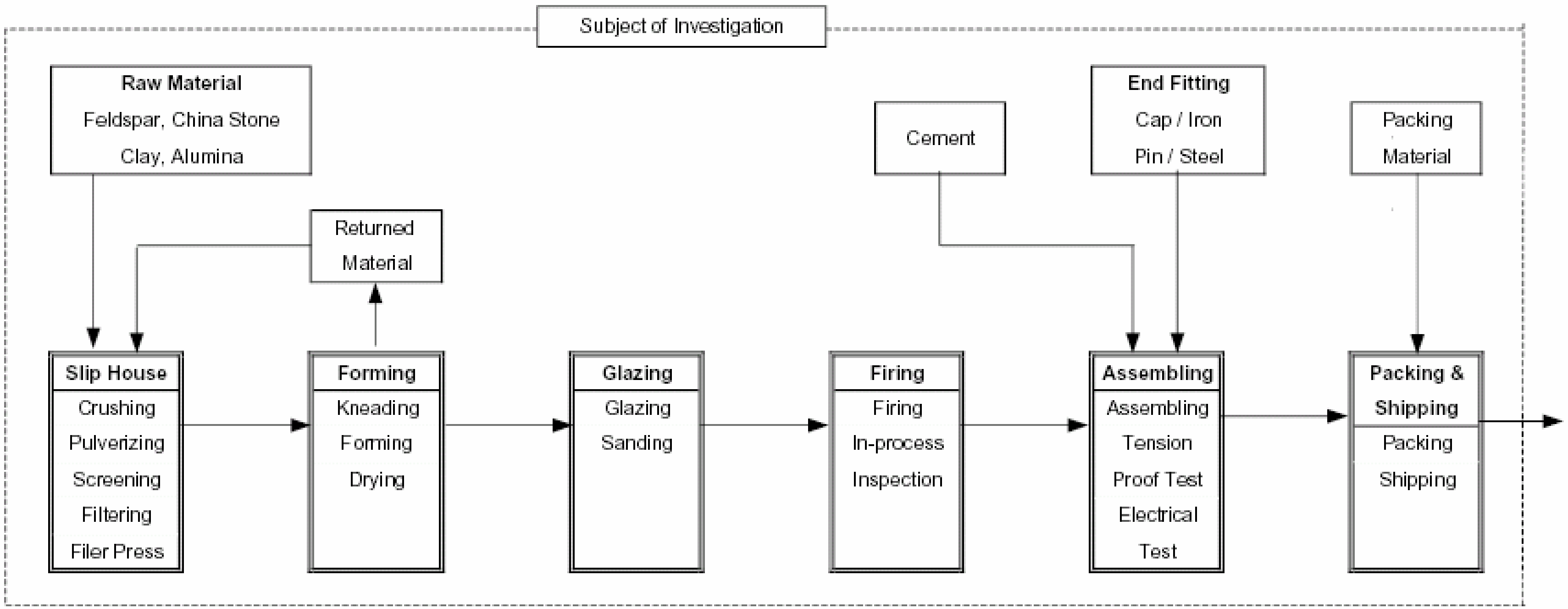


Figure 17: LCA of Insulator (Porcelain Disc)

7.1.4.3 Inventory list

The main inventories included in the calculation are shown below.

- Resource exhaustion
  - (Iron, Aluminum, Manganese, Zinc, Lead, Oil, Coal, Natural gas, Uranium)
- Air pollution
  - (CO_2, NO_x, SO_2, etc.)

For the results, please see subsections for each component.

7.1.4.4 Data collection procedures

The input and output data in each process analyzed that are peculiar to overhead transmission line components are collected using the process analysis method. For processes that are not peculiar to transmission lines components but are widely used in various industries, the basic database of the LCA software (JEMAI-LCA) is used.

[Processes peculiar to overhead transmission lines in this study]

- Parts manufacturing for lattice tower (eg: Steel angle member, plate, and bolt manufacturing)
- Conductor manufacturing (eg: Aluminum strands, steel strands, and stranded wires)
- Insulator manufacturing (eg: Material crushing, forming, glazing, firing, and assembling)
- Use (transmission loss)

7.1.4.5 Allocation procedures of coproducts

With regard to coproducts, the environmental burden in the manufacturing process of coproducts is proportionally allocated.

7.1.4.6 Allocation procedures for recycling processes

90% of lattice towers and conductor are recycled and environmental burden, which corresponds to the volume of recycled iron ingot, aluminum ingot, and zinc, is deducted from the original environmental burden.

7.1.4.7 Allocation procedure to each country

Japan imports a large amount of raw materials from overseas. All the electric energy, inputs of raw materials and outputs to the atmosphere, water and ground, which are related to the imported material, are added up respectively through its upstream processes and distributed to the importing countries according to the ratio settled for the imported material.

For example, if Japan imports 70% of aluminum ingot from country A and the remaining 30% from country B, all the energy consumption, resourse exhaustion, and emission related to the aluminum ingot production processes (from bauxite mining to aluminum refining) are distributed in the two countries according to the proportion of 70 : 30.

7.1.4.8 Marine transportation of raw materials or intermediate products

Transportation of raw materials or intermediate products by sea is taken into consideration as a form of gas (CO_2, NO_x, SO_2, etc.) emission to the air. This emission caused by heavy oil and LNG combustion of marine transportation is classified into "open sea" in inventory analysis.

7.1.4.9 Power generation process

Electricity used for the imported material is also all added up and distributed to the importing countries according to the procedure outlined in **7.1.4.7 Allocation procedure to each country**. Then the electricity is converted to inventory items (inputs of raw materials and outputs to the atmosphere) taking the electric power situation in the importing country into consideration. As a database, the software (JEMAI-LCA) has power generation source composition (MJ) for generating 1kWh of electricity under each country's situation. Its original data is from the OECD statistics (1996). Using the database, electricity is converted to amount of energy (MJ) by each power generation source, and then they are converted to the amount of required fuel (input) and the amount of each emission to the atmosphere (output) for each power source. The conversion factors to each emission are cited from BUWAL-132. Each output (emission) per unit energy amount for representative power generation sources (nuclear power, coal, oil and natural gas) is shown in the following table. This means that electricity is adjusted by taking the power generation source composition and power generation efficiency of each importing country into account.

Unit (kg)

Generation Type	Low-level Radioactive	CO_2	CO	CxHy	Dust	N_2O	NOx	SO_2
Nuclear Power	1.903e-6	---	---	---	---	---	---	---
Thermal Coal	---	0.09063	92.1e-6	0.921e-6	39.6e-6	13.815e-6	267.1e-6	497.3e-6
Thermal Oil	---	0.0717	13.7e-6	0.9131e-6	18.2e-6	13.7e-6	182.62e-6	666.56e-6
Thermal LNG	---	0.04935	26.784e-6	5.3568e-6	---	4.464e-6	169.632e-6	---

Table 8: Exhausted Quantities of Substance for Each Power Generation System

7.1.5 Methodology for impact assessment

7.1.5.1 Impact category for environmental burdens

The following are the impact categories considered in this LCA.

- Resource exhaustion
- Global warming
- Acid rain
- Eutrophication of lakes and marshes
- Toxicity to human body
- Solid wastes

7.1.5.2 Category indicators for converting the data to the impact categories

The category indicators used to convert inventory data into the above impact categories are:

- Resource exhaustion → Inverse of total deposits in the world
- Global warming → Global Warming Potential (the IPCC 1992 report 100-year GWP)
- Acid rain → Acidification Potential: Leiden University Institute CML (CML Method)
- Eutrophication of lakes and marshes → Leiden University Institute CML (CML Method)
- Toxicity to human body → Leiden University Institute CML (CML Method)
- Solid wastes → Weight (kg)

IPCC: Intergovernmental Panel on Climate Change

Leiden University Institute CML (Center of Environmental Science)

Characterization factor CML potential (1992) by R. Heijungs

7.2 Results of Analysis, Impact Assessment and Conclusions - Lattice Steel Tower

7.2.1 Results of inventory analysis

7.2.1.1 Analysing results by each process (Recycling processes are not considered)

Table 9 and ***Figures 18*** and ***19*** show the results of the analysis. These results indicate that coal for coke reserves, which is used for pig iron production in the furnace, and Fe reserves are mainly consumed in the steel member manufacturing process, which uses more iron than the other three processes (steel plate, steel bolt, and foundation). On the other hand, for oil reserves the steel plate manufacturing process consumes more oil than other processes because the process needs more energy for its shear and bending work. In ***Figure 19*** (Emission to air), SO_2 pollution is the significant feature with the major proportion arising from ”open sea”, see the footnote to ***Figure 19***. In this LCA software, it is assumed that oil combustion for marine transportation exhausts more SO_2 than other energy processes such as combustion for electricity generation.

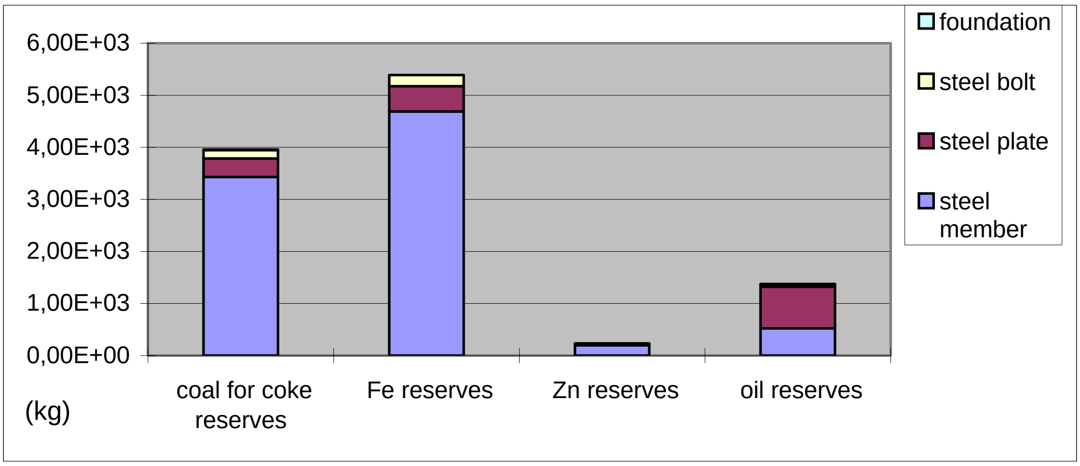
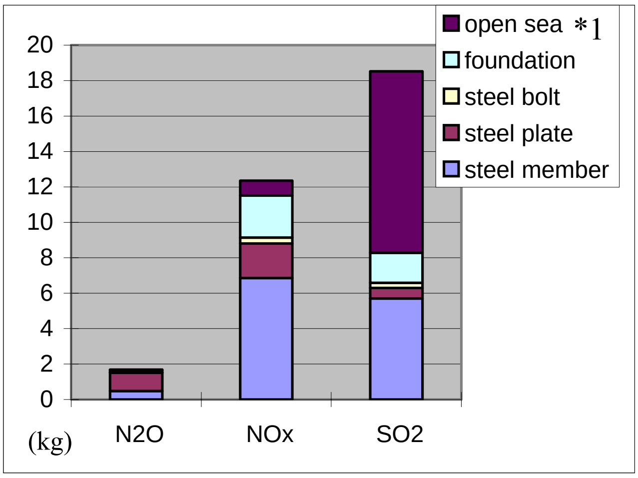
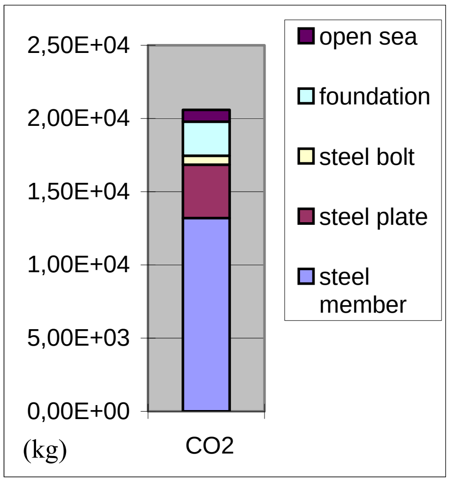


Figure 18: Inventory analysis of resource exhaustion





*1 Open sea: When intermediate products or materials are imported from abroad, gas from heavy oil combustion of marine transportation is classified into "open sea".

Figure 19: Inventory analysis of air pollution

Lattice Steel Tower - Inventory Result									
	No	item	unit	total	steel member	steel plate	steel bolt	foundation	open sea
raw material [resource exhaustion]	1	coal for coke reserves	kg	3.96E+03	3.43E+03	3.55E+02	1.60E+02	1.34E+01	
	2	coal for elect. reserves	kg	1.32E+03	832.1241	84.1976	41.1578	357.8471	
	3	Fe reserves	kg	5.39E+03	4.69E+03	484.6993	215.4219		
	4	LNG reserves kg	kg	176.0814	139.6029	25.2064	6.9389	4.3333	
	5	Mn reserves	kg	34.3231	29.8611	3.0891	1.3729		
	6	oil reserves	kg	1.38E+03	522.2694	802.395	22.1769	29.9364	
	7	Pb reserves	kg	27.49	23.4181	2.4226	1.6493		
	8	U reserves	kg	0.0183	0.0155	0.0015	7.88E-04	5.12E-04	
	9	Zn reserves	kg	232.184	197.7922	20.4613	13.9306		
emission to air	1	CH4	kg	0.0484	0.0411	0.0039	0.0021	0.0014	
	2	CO2	kg	2.06E+04	1.32E+04	3.64E+03	619.4109	2.33E+03	799.0269
	3	N2O	kg	1.6892	0.4759	1.03	0.0184	0.1456	0.0193
	4	No x	kg	12.345	6.8583	1.9487	0.3313	2.3709	0.8357
	5	SO2	kg	18.5209	5.7026	0.595	0.2951	1.6937	10.2344
	6	As	kg	9.98E-06	8.47E-06	8.04E-07	4.28E-07	2.82E-07	
	7	Cd	kg	4.99E-07	4.23E-07	4.02E-08	2.14E-08	1.41E-08	
	8	CO	kg	3.676	2.1823	0.3603	0.1059	0.8934	0.1341
	9	Cr	kg	9.98E-06	8.47E-06	8.04E-07	4.28E-07	2.82E-07	
	10	Hg	kg	9.98E-06	8.47E-06	8.04E-07	4.28E-07	2.82E-07	
	11	Ni	kg	4.49E-04	3.81E-04	3.62E-05	1.93E-05	1.27E-05	
	12	Pb	kg	2.99E-05	2.54E-05	2.41E-06	1.29E-06	8.46E-07	
	13	V	kg	2.50E-04	2.12E-04	2.01E-05	1.07E-05	7.05E-06	
	14	Zn	kg	4.99E-05	4.23E-05	4.02E-06	2.14E-06	1.41E-06	

graphed, see Figures 18 and 19

*1 Open sea: When intermediate products or materials are imported from abroad gas from heavy oil combustion of marine transportation is classified into "open sea".

Table 9: Result of inventory analysis

7.2.1.2 Results of domestic and overseas analysis (Recycling processes are not considered)

Table 10 and ***Figure 20*** and ***21*** show domestic and overseas(abroad) comparisons of inventory analysis. The results indicate that overseas account for the major part of the resource consumption (See ***Figure 20***). On the other hand, domestic accounts for the largest amount of most of the air pollution shown in ***Figure 21***. This means that lattice steel tower manufacturing processes such as shear, bend, chemical pretreatment, or others. which are dealt with domestically, have more impact on this area.

Lattice Steel Tower - Inventory Result (Region)							
	No	**item**	**unit**	**total**	**domestic**	**abroad**	**open sea**
raw material [resource exhaustion]	1	coal for coke reserves	kg	3.96E+03		3.96E+03	
	2	coal for elect. reserves	kg	1.32E+03	168.3448	1.15E+03	
	3	Fe reserves	kg	5.39E+03		5.39E+03	
	4	LNG reserves kg	kg	176.0814	0.1694	175.912	
	5	Mn reserves	kg	34.3231		34.3231	
	6	oil reserves	kg	1.38E+03	0.3757	1.38E+03	
	7	Pb reserves	kg	27.49		27.49	
	8	U reserves	kg	0.0183	0.0181	2.25E-04	
	9	Zn reserves	kg	232.184	28.7899	203.3941	
emission to air	1	CH4	kg	0.0484	0.0484		
	2	CO2	kg	2.06E+04	1.90E+04	813.8887	799.0269
	3	N2O	kg	1.69E+00	1.51E+00	0.1583	0.0193
	4	NOx	kg	1.23E+01	8.61E+00	2.9005	0.8357
	5	SO2	kg	1.85E+01	5.68E+00	2.6019	10.2344
	6	As	kg	9.98E-06	9.98E-06		
	7	Cd	kg	4.99E-07	4.99E-07		
	8	CO	kg	3.676	2.6141	0.9277	0.1341
	9	Cr	kg	9.98E-06	9.98E-06		
	10	Hg	kg	9.98E-06	9.98E-06		
	11	Ni	kg	4.49E-04	4.49E-04		
	12	Pb	kg	2.99E-05	2.99E-05		
	13	V	kg	2.50E-04	2.50E-04		
	14	Zn	kg	4.99E-05	4.99E-05		

Table 10: Comparison between domestic and overseas

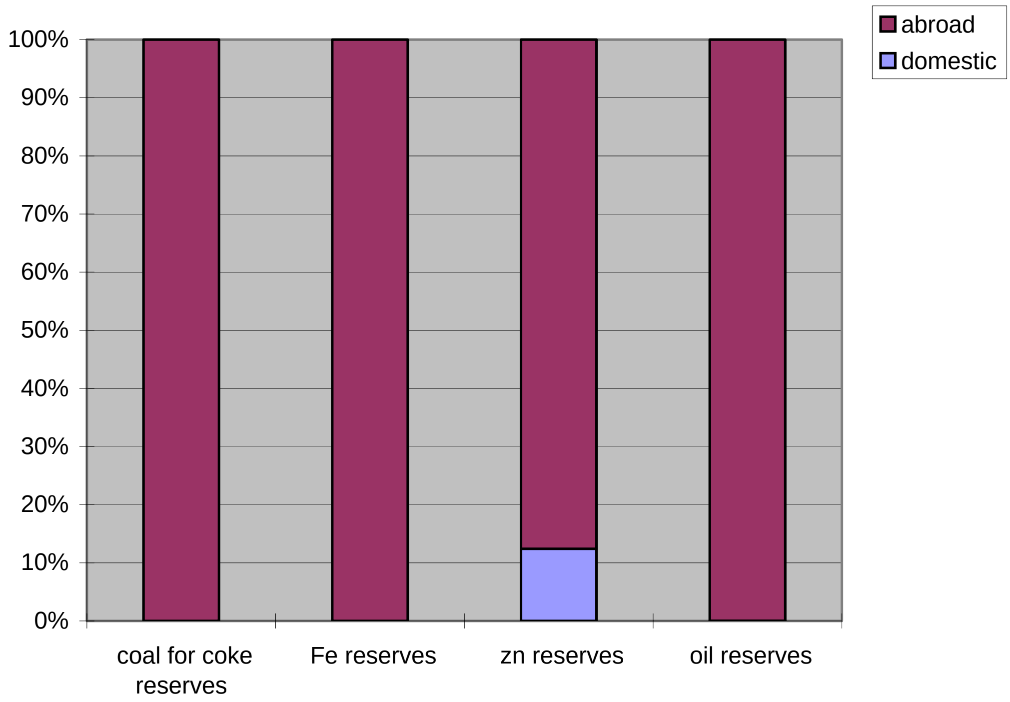


Figure 20: Resource exhaustion between domestic and overseas

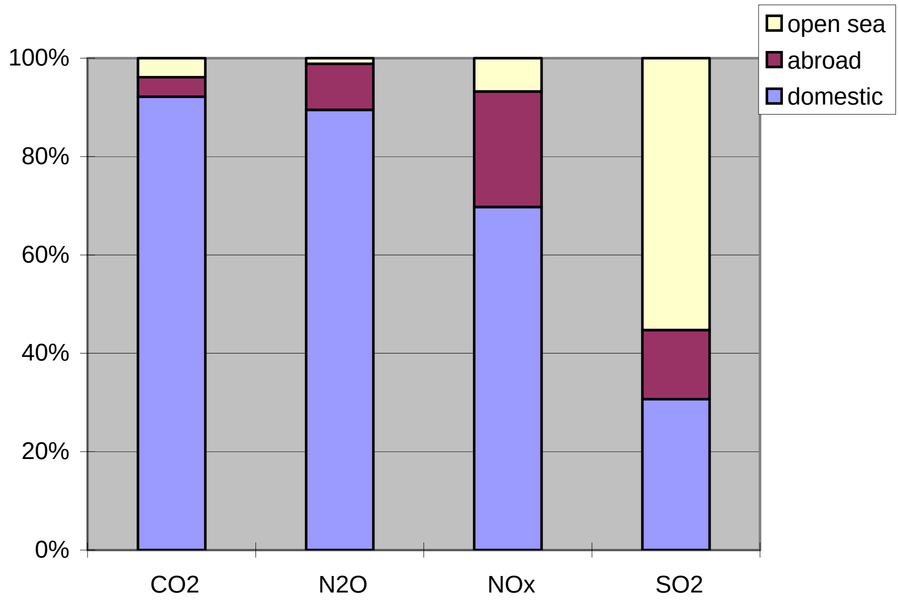


Figure 21: Air pollution between domestic and overseas

7.2.1.3 Effect of recycling processes

Considering recycling processes as outlined in **7.1.3.3 System boundaries**, **Figure 22** shows the effect of recycling processes. Since steel members are recycled at a high rate, resource exhaustion for Fe (Iron Ore) is largely reduced in the recycling case. A similar trend is seen for Zn (zinc), which is used for galvanisation of the steel members. However we can notice that oil for electricity and emissions to the air do not decrease to any great degree compared to Fe or Zn. This result is mainly derived from how iron is recycled in Japan. Original iron is produced through a blast furnace process, which consumes large amount of coke, while recycled iron is produced through an electric arc furnace. This means that the recycling case reduces considerably coal for coke however it does not reduce resource or emissions, which are related to electricity power generation.

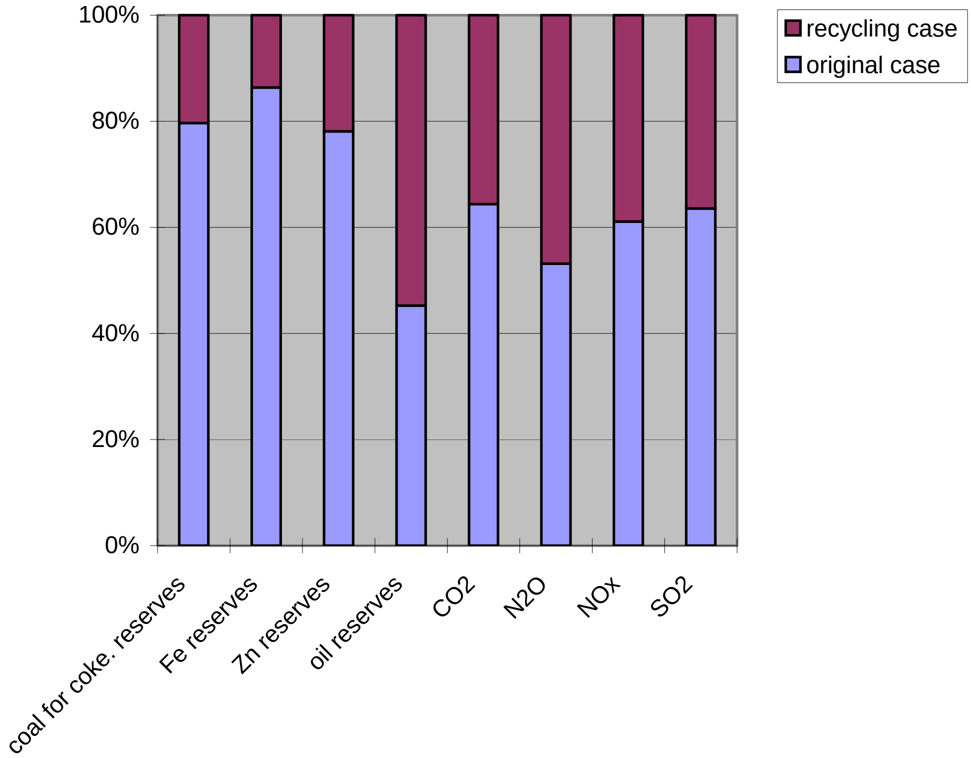


Figure 22: Comparison between original case and recycling case

7.2.2 Impact assessment Result (Recycling processes are not considered)

7.2.2.1 Resource exhaustion

Table 11 and ***Figure 23*** show the results of analysis. In **Table 11**, although the quantity of coal, heavy oil and Fe is larger than that of zinc, the impact on resource exhaustion is the greatest for zinc, followed by lead. This is caused by the characterisation factors used in the study.

Lattice Steel Tower resource exhaustion－impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
Raw material [resource exhaustion]	coal for coke reserves	3.96E+03	kg	1.93E-03	7.64E+00
	coal for elect. reserves	1.32E+03	kg	1.93E-03	2.54E+00
	Fe reserves	5.39E+03	kg	1.32E-02	7.10E+01
	LNG reserves kg	1.76E+02	kg	9.70E-06	1.71E-03
	Mn reserves	3.43E+01	kg	2.00E-01	6.86E+00
	oil reserves	1.38E+03	kg	7.26E-03	1.00E+01
	Pb reserves	2.75E+01	kg	7.14E+00	1.96E+02
	U reserves	1.83E-02	kg	2.22E+02	4.06E+00
	Zn reserves	2.32E+02	kg	2.27E+00	5.28E+02
				total	8.26E+02

Table 11: Impact on resource exhaustion

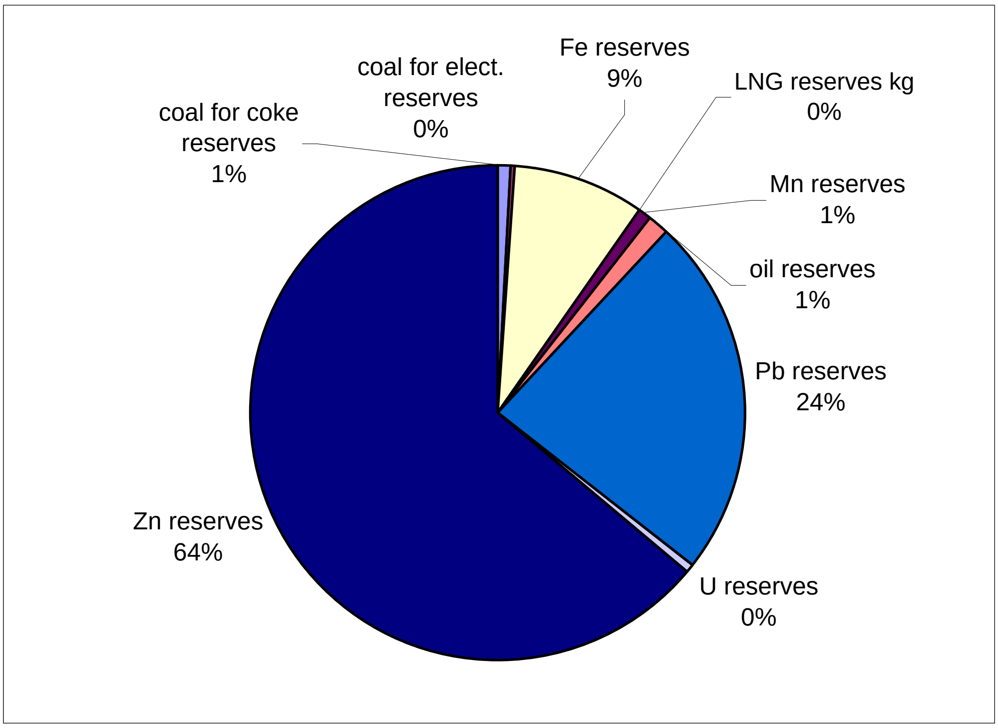


Figure 23: Impact on resource exhaustion

7.2.2.2 Global warming

Table 12 and ***Figure 24*** show the results of analysis. The CO_2 emissions are remarkably large in comparison with those of other gases and have a dominant impact on global warming.

Lattice Steel Tower global warming－impact assessment					
	Item	**quantity**	**unit**	**characterization factor**	**category indicators**
Emission to air	CH4	4.84E-02	kg	1.10E+01	5.32E-01
	CO2	2.06E+04	kg	1.00E+00	2.06E+04
	N2O	1.69E+00	kg	2.70E+02	4.56E+02
				total	2.11E+04

Table 12: Impact on global warming

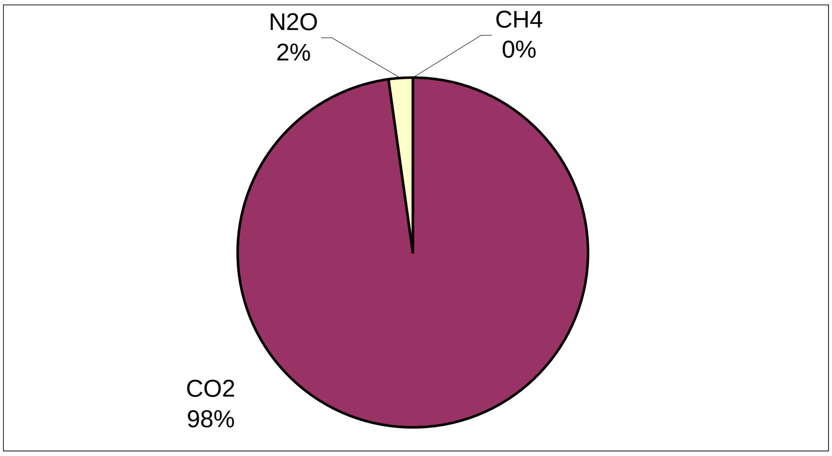


Figure 24: Impact on global warming

7.2.2.3 Acid rain

The results of the analysis are shown in **Table 13** and ***Figure 25***. Emissions having some connection with acid rain are only NO_x and SO_2 in this study, and these two compounds are totally responsible for this environmental impact.

Lattice Steel Tower acid rain－impact assessment					
	Item	**quantity**	**unit**	**characterization factor**	**category indicators**
Emission to air	Nox	1.23E+01	kg	7.00E-01	8.64E+00
	SO2	1.85E+01	kg	1.00E+00	1.85E+01
				total	2.72E+01

Table 13: Impact on acid rain

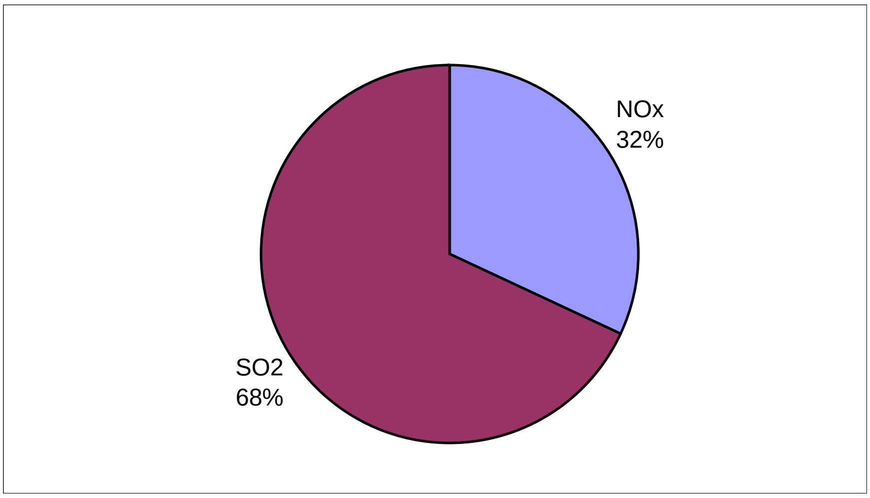


Figure 25: Impact on acid rain

7.2.2.4 Eutrophication of lakes and marshes

Table 14 suggests that NO_x is the only emission that relates to the eutrophication of lakes and marshes.

Lattice Steel Tower eutrophication－impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
emission to air	NOx	1.23E+01	kg	1.30E-01	1.60E+00
				total	1.60E+00

Table 14: Impact on eutrophication

7.2.2.5 Toxicity to human body

Table 15 and ***Figure 26*** show the results of analysis. While the graph indicates that NO_x and SO_2 are the main emissions relevant to such toxicity, the table suggests the existence of several other substances that have some impact on this category. The emissions of these substances are remarkably lower than those of NO_x or SO_2, therefore the proportion of these substances in the overall impact is 1 % or less.

Lattice Steel Tower toxicity to human－ impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
Emission To air	As	9.98E-06	kg	4.70E+03	4.69E-02
	Cd	4.99E-07	kg	5.80E+02	2.89E-04
	CO	3.68E+00	kg	1.20E-02	4.41E-02
	Cr	9.98E-06	kg	6.70E+00	6.69E-05
	Hg	9.98E-06	kg	1.20E+02	1.20E-03
	Ni	4.49E-04	kg	4.70E+02	2.11E-01
	NOx	1.23E+01	kg	7.80E-01	9.63E+00
	Pb	2.99E-05	kg	1.60E+02	4.79E-03
	SO2	1.85E+01	kg	1.20E+00	2.22E+01
	V	2.50E-04	kg	1.20E+02	2.99E-02
	Zn	4.99E-05	kg	3.30E-02	1.65E-06
				total	3.22E+01

Table 15: Impact on toxicity to human

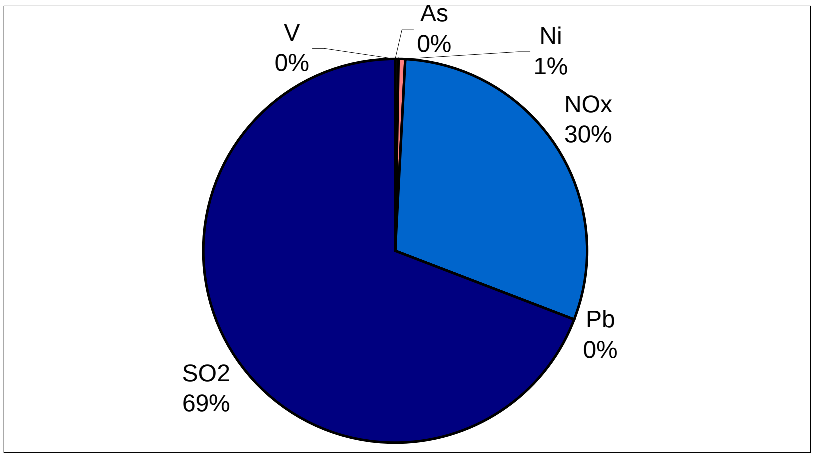


Figure 26: Impact on toxicity to human

7.2.2.6 Solid wastes

Table 16 indicates the results of the analysis. Slag is the only substance in this category. Slag is produced in the production of steel ingots, and zinc. As the category indicator simply considers weight, it is 1.0.

Lattice Steel Tower solid waste - impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
solid waste	slag	2.16E+03	kg	1.00E+00	2.16E+03
				total	2.16E+03

Table 16: Impact on solid waste

7.2.3 Impact of recycling processes

Considering recycling processes as outlined in **7.1.3.3 System boundaries**, ***Figure 27*** shows the effect of recycling processes. Since the amount of natural resources used is largely reduced (as stated in **7.2.1.3 Effect of recycling processes**) by the introduction of a recycling procedure, in the resource exhaustion category, impact on the environment is also reduced largely in the recycling case. However for the categories, which are related to emissions to the air, environmental impact does not greatly decrease because the iron-recycling process itself consumes a certain amount of electric energy for its electric arc furnace process.

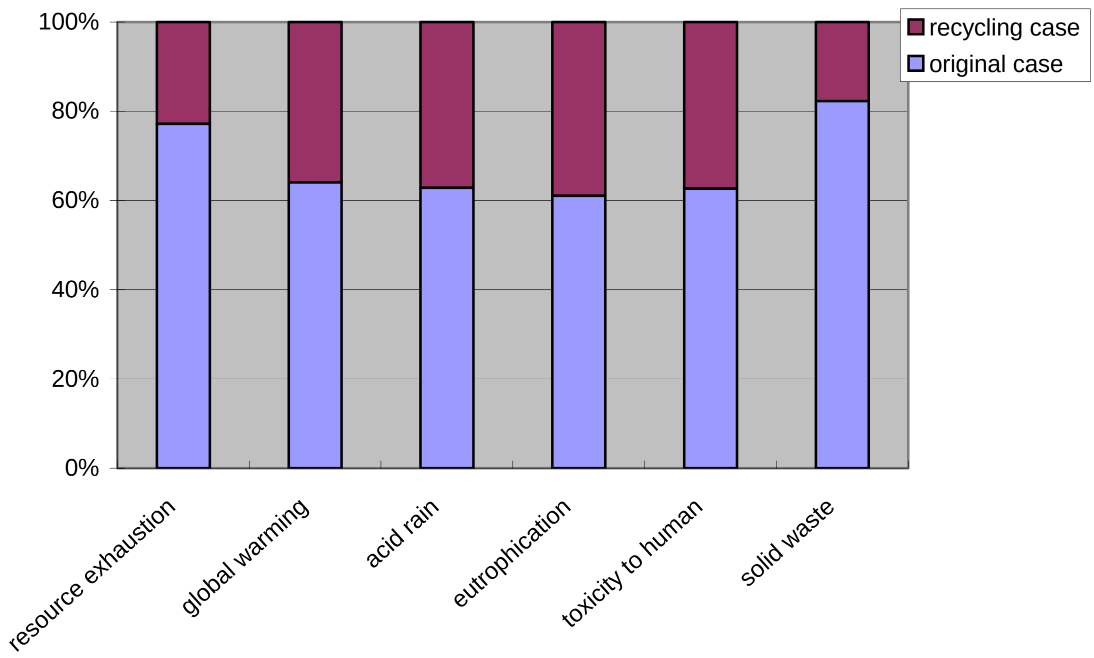


Figure 27: Comparison between original case and recycling case

7.2.4 Conclusions and Recommendation

7.2.4.1 Conclusions

- Because of the large quantity of iron used in a lattice steel tower, the resources required for iron production such as coal for coke reserves and Fe reserves are consumed largely in the steel angle member manufacturing process as compared to resource exhaustion in the manufacturing processes of other parts of the tower.

- Concerning emissions to the air, the lattice steel tower manufacturing processes such as shear, bending, chemical pretreatment etc., which are dealt with domestically, have more influence on this area and this results in more domestic emissions of gas (such as CO_2, NO_x, SO_2) to air.
- The environmental impact from resource exhaustion could be largely reduced by the introduction of a recycling process although other environmental impacts, which are related to emissions to the air, do not seem to be reduced as much as resource exhaustion does.

7.2.4.2 Recommendation

To reduce environmental impact, especially to reduce resource exhaustion impact, it is strongly recommended that lattice steel towers should be recycled. It could reduce the amount of iron reserves consumption as well as zinc reserves consumption. In this case study, it is presumed that zinc is recycled, however recycling zinc is not as common as recycling steel. The extent of zinc deposits in the world is much less than those of iron and taking this situation into consideration it is also recommended that zinc recycling processing should be widely adopted.

7.3 Results of Analysis, Impact Assessment and Conclusions - Conductor (ACSR)

7.3.1 Results of inventory analysis

7.3.1.1 Analysing results by each process (Recycling processes are not considered)

Table 17 and ***Figures 28*** and ***29*** show the results of the analysis. These results indicate that a large part of resources (aluminum and iron) are consumed in the manufacturing process of strands (aluminum strands and steel strands), at the same time, coal and heavy oil are also mainly consumed in manufacturing aluminum strands.

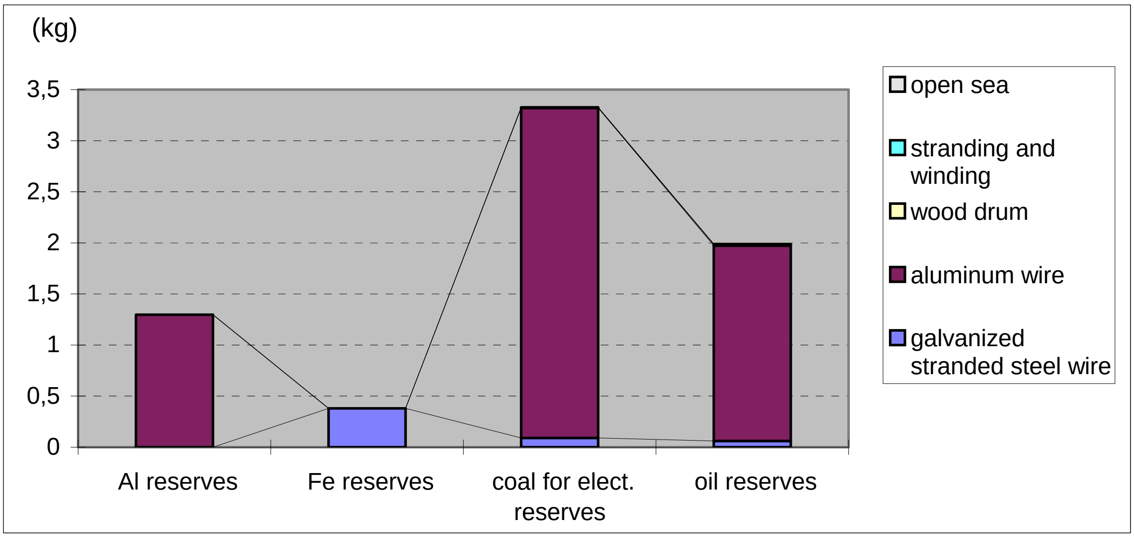
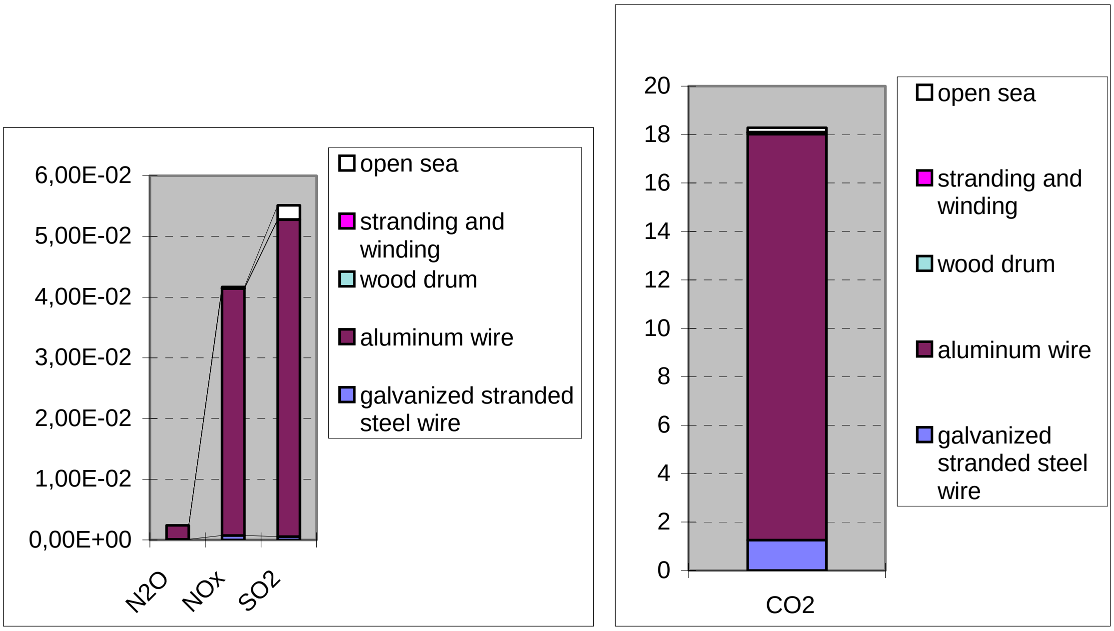


Figure 28: Inventory analysis of resource exhaustion



*1 Open sea: When intermediate products or materials are imported from abroad, gas from heavy oil combustion of marine transportation is classified into "open sea".

Figure 29: Inventory analysis of air pollution in kg

ACSR410mm2 (1m) inventory result										*1
	No	**item**	**unit**	**total**	**galvanized stranded steel wire**	**aluminum wire**	**wood drum**	**stranding and winding**	**open sea**
raw material [resource exhaustion]	1	Al reserves	kg	1.2973		1.2973			
	2	coal for coke reserves	kg	0.2823	0.2792	0.0031			
	3	coal for elect. reserves	kg	3.327	0.0905	3.2294	0.0038	0.0033	
	4	Fe reserves	kg	0.3808	0.3808				
	5	LNG reserves kg	kg	1.0119	0.0419	0.9663	0.002	0.0016	
	6	Mn reserves	kg	0.0024	0.0024				
	7	oil reserves	kg	1.989	0.0606	1.9122	0.0125	0.0037	
	8	Pb reserves	kg	0.0022	0.0022				
	9	U reserves	kg	1.36E-05	2.78E-06	1.03E-05	2.59E-07	2.21E-07	
	10	Zn reserves	kg	0.017	0.017				
emission to air	1	CH4	kg	1.28E-05	7.41E-06	4.13E-06	6.94E-07	5.92E-07	
	2	CO2	kg	18.2793	1.2566	16.7625	0.0561	0.0254	0.1786
	3	N2O	kg	0.0024	9.51E-05	0.0023	5.93E-06	2.78E-07	7.26E-06
	4	NOx	kg	0.0417	7.27E-04	0.0407	4.62E-05	1.54E-05	1.95E-04
	5	SO2	kg	0.0551	5.62E-04	0.0522	3.25E-05	1.94E-05	0.0023
	6	As	kg	2.64E-09	1.53E-09	8.52E-10	1.43E-10	1.22E-10	
	7	Cd	kg	1.32E-10	7.63E-11	4.26E-11	7.16E-12	6.11E-12	
	8	CO	kg	0.01	2.12E-04	0.0098	9.55E-06	3.76E-06	3.31E-05

ACSR410mm2 (1m) inventory result									*1
	No	**item**	**unit**	**total**	**galvanized stranded steel wire**	**aluminum wire**	**wood drum**	**stranding and winding**	**open sea**
	9	Cr	kg	2.64E-09	1.53E-09	8.52E-10	1.43E-10	1.22E-10	
	10	Hg	kg	2.64E-09	1.53E-09	8.52E-10	1.43E-10	1.22E-10	
	11	Ni	kg	1.19E-07	6.87E-08	3.83E-08	6.44E-09	5.50E-09	
	12	Pb	kg	7.93E-09	4.58E-09	2.56E-09	4.29E-10	3.66E-10	
	13	V	kg	6.61E-08	3.82E-08	2.13E-08	3.58E-09	3.05E-09	
	14	Zn	kg	1.32E-08	7.63E-09	4.26E-09	7.16E-10	6.11E-10	

: graphed, see **Figures 28 and 29**

*1 Open sea: When intermediate products or materials are imported from abroad, gas from heavy oil combustion of marine transportation is classified into "open sea".

Table 17: Result of inventory analysis

This is caused by the large consumption of energy in the manufacturing process of aluminum ingots from bauxite. It also leads to the emission of CO_2, N_2O, NO_x, and SO2 into the air, most of which are the result of aluminum strand manufacturing (aluminum ingot production).

7.3.1.2 Results of regional analysis (Recycling processes are not considered)

Table 18 and ***Figure 30*** and ***31*** show domestic and overseas comparisons of the results of the inventory analysis. The results indicate that overseas accounts for the most part of the resource consumption and the emission into the air.

ACSR410mm2 (1m) inventory result(region)							
	No	**item**	**unit**	**total**	**domestic**	**abroad**	**open sea**
raw material [resource exhaustion]	1	Al reserves	kg	1.2973		1.2973	
	2	coal for coke reserves	kg	0.2823		0.2823	
	3	coal for elect. reserves	kg	3.327	0.0125	3.3145	
	4	Fe reserves	kg	0.3808		0.3808	
	5	LNG reserves kg	kg	1.0119	2.46E-05	1.0119	
	6	Mn reserves	kg	0.0024		0.0024	
	7	oil reserves	kg	1.989	3.17E-04	1.9886	
	8	Pb reserves	kg	0.0022	1.21E-05	0.0021	
	9	U reserves	kg	1.36E-05	4.79E-06	8.79E-06	
	10	Zn reserves	kg	0.017	0.0021	0.0149	
emission to air	1	CH4	kg	1.28E-05	1.28E-05		
	2	CO2	kg	18.2793	1.831	16.2697	0.1786
	3	N2O	kg	0.0024	1.62E-04	0.0023	7.26E-06
	4	NOx	kg	0.0417	0.0015	0.04	1.95E-04
	5	SO2	kg	0.0551	7.36E-04	0.052	0.0023
	6	As	kg	2.64E-09	2.64E-09		
	7	Cd	kg	1.32E-10	1.32E-10		
	8	CO	kg	0.01	2.12E-04	0.0098	3.31E-05
	9	Cr	kg	2.64E-09	2.64E-09		
	10	Hg	kg	2.64E-09	2.64E-09		
	11	Ni	kg	1.19E-07	1.19E-07		
	12	Pb	kg	7.93E-09	7.93E-09		
	13	V	kg	6.61E-08	6.61E-08		
	14	Zn	kg	1.32E-08	1.32E-08		

Table 18: Comparison between domestic and overseas

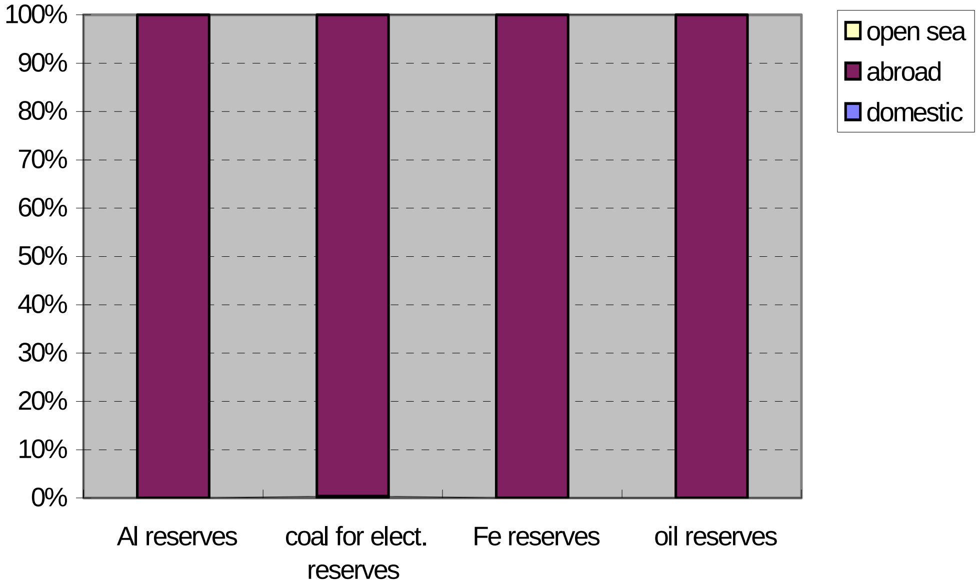


Figure 30: Resource exhaustion between domestic and overseas

For the same reason, as stated in **7.3.1.1 Analysing results by each process**, the processes relating to the production of aluminum ingots (overseas) from bauxite have a dominant effect on the results.

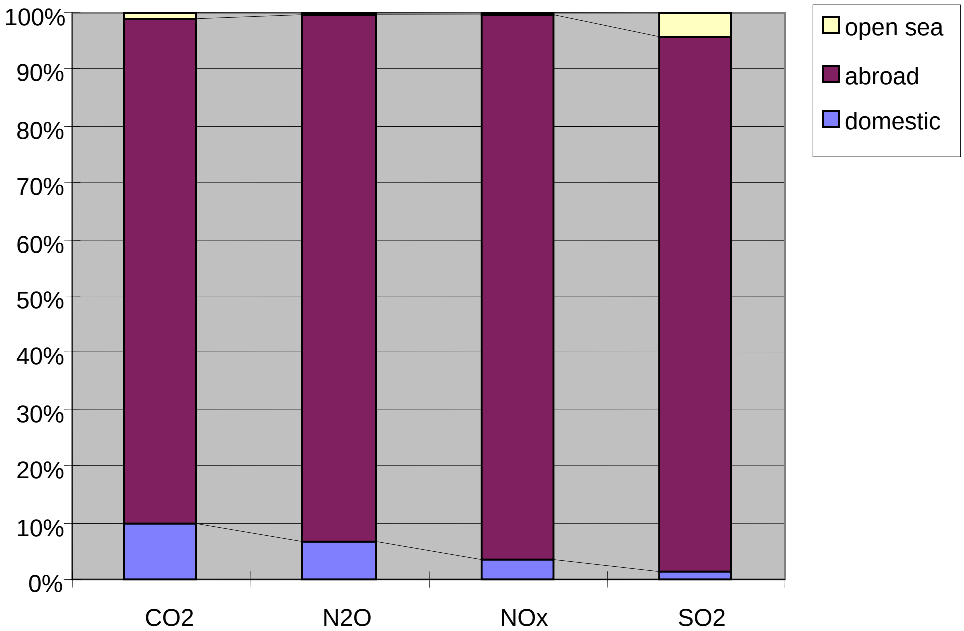


Figure 31: Air pollution between domestic and overseas

7.3.1.3 Effect of recycling processes

Considering recycling processes described in **7.1.3.3 System boundaries**, ***Figure 32*** shows the effect of recycling processes. Since aluminum is recycled at a high rate, resource exhaustion for aluminum and emissions related to aluminum production are drastically reduced in the recycling case.

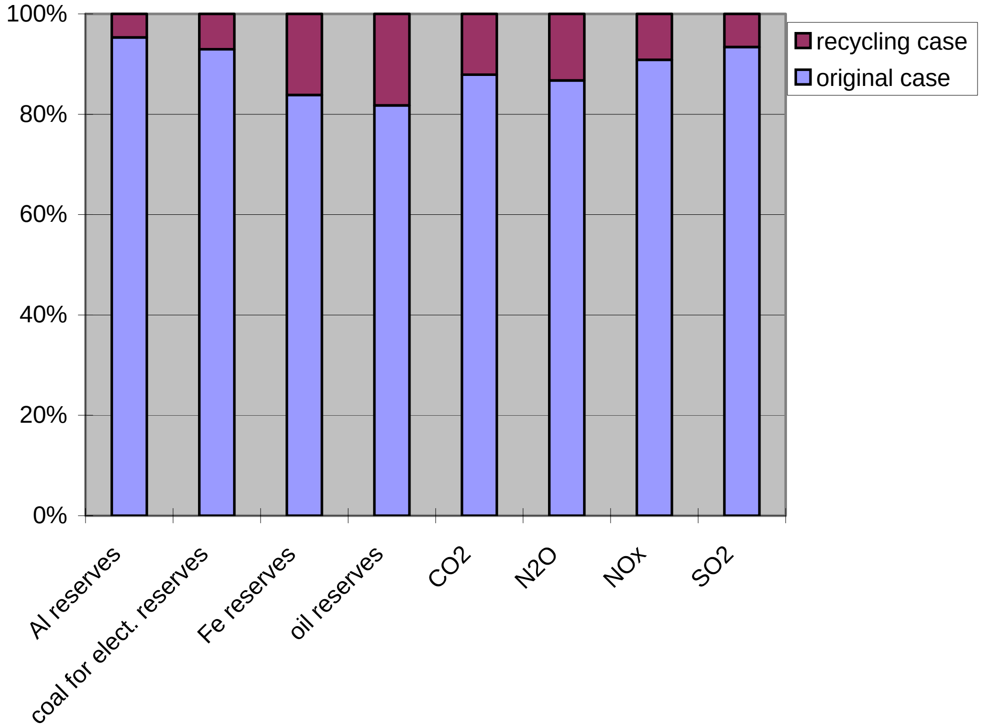


Figure 32: Comparison between original case and recycling case

7.3.2 Impact assessment results (Recycling processes are not considered)

7.3.2.1 Resource exhaustion

Table 19 and ***Figure 33*** show the results of the analysis. Although the results of the inventory analysis indicate that there is a greater consumption of coal, heavy oil and aluminum, the impact on resource exhaustion is the greatest for aluminum, followed by zinc and lead. This is caused by the characterization factors used in the study.

ACSR410mm2 (1m) resource exhaustion - impact assessment					
	Item	**Quantity**	**Unit**	**Characterisation factor**	**Category indicators**
Raw material [resource exhaustion]	Al reserves	1.30E+00	kg	2.94E-02	3.82E-02
	coal for coke reserves	2.82E-01	kg	1.93E-03	5.45E-04
	coal for elect. reserves	3.33E+00	kg	1.93E-03	6.42E-03
	Fe reserves	3.81E-01	kg	1.32E-02	5.02E-03
	LNG reserves kg	1.01E+00	kg	9.70E-06	9.82E-06
	Mn reserves	2.43E-03	kg	2.00E-01	4.85E-04
	oil reserves	1.99E+00	kg	7.26E-03	1.44E-02
	Pb reserves	2.16E-03	kg	7.14E+00	1.54E-02
	U reserves	1.36E-05	kg	2.22E+02	3.01E-03
	Zn reserves	1.70E-02	kg	2.27E+00	3.86E-02
				Total	1.22E-01

Table 19: Impact on resource exhaustion

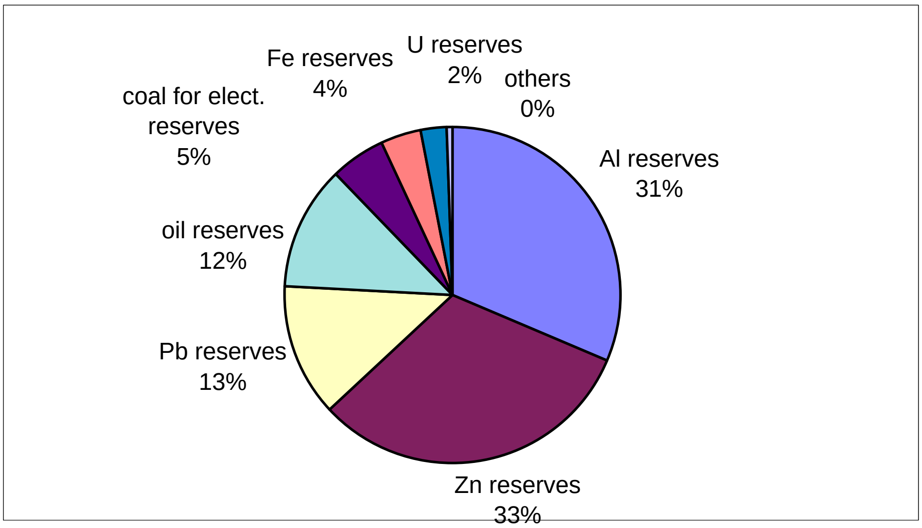


Figure 33: Impact on resource exhaustion

7.3.2.2 Global warming

Table 20 and ***Figure 34*** show the results of the analysis. The CO_2 emissions are remarkably large in comparison with those of other gases and have a dominant impact on global warming.

ACSR410mm2 (1m) global warming - impact assessment					
	Item	**Quantity**	**Unit**	**Characterisation factor**	**Category indicators**
emission to air	CH4	1.28E-05	kg	1.10E+01	1.41E-04
	CO2	1.83E+01	kg	1.00E+00	1.83E+01
	N2O	2.44E-03	kg	2.70E+02	6.57E-01
				total	1.89E+01

Table 20: Impact on global warming

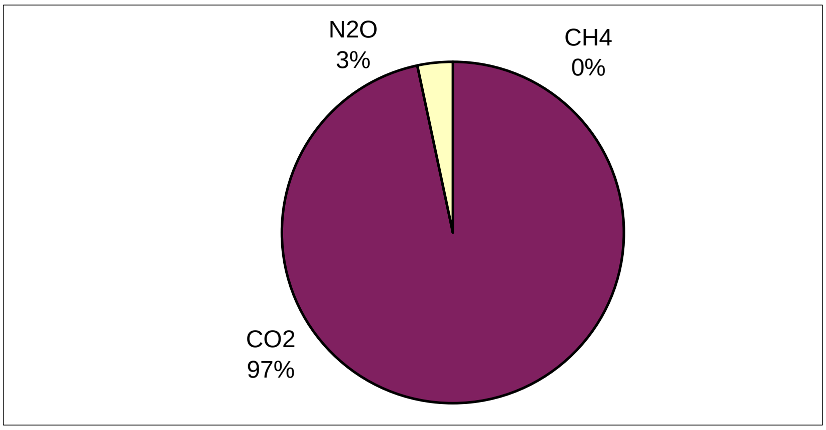


Figure 34: Impact on global warming

7.3.2.3 Acid rain

The results of the analysis are shown in **Table 21** and ***Figure 35***. Emissions having some connection with acid rain are only NO_x and SO_2 in this study, and these two compounds are totally responsible for the environmental impact.

ACSR410mm2 (1m) acid rain－ impact assessment					
	Item	**Quantity**	**Unit**	**Characterisation factor**	**Category indicators**
emission to air	Nox	4.17E-02	kg	7.00E-01	2.92E-02
	SO2	5.51E-02	kg	1.00E+00	5.51E-02
				total	8.43E-02

Table 21: Impact on acid rain

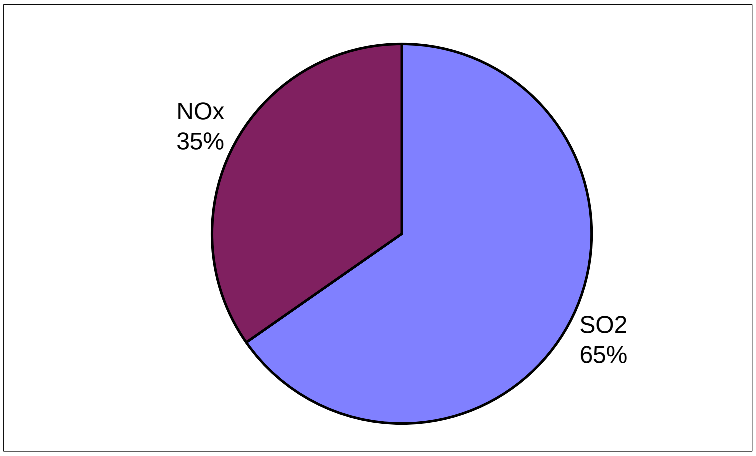


Figure 35: Impact on acid rain

7.3.2.4 Eutrophication of lakes and marshes

Table 22 suggests that NO_x is the only emission that relates to the eutrophication of lakes and marshes.

ACSR410mm2 (1m) eutrophication－ impact assessment					
	Item	**Quantity**	**Unit**	**Characterisation factor**	**Category indicators**
emission to air	NOx	4.17E-02	kg	1.30E-01	5.42E-03
				total	5.42E-03

Table 22: Impact on eutrophication

7.3.2.5 Toxicity to human body

Table 23 and ***Figure 36*** show the results of analysis. While the graph indicates that NO_x and SO_2 are the only emissions relevant to such toxicity, the table suggests the existence of several other substances that have some small impact on this category. The emissions of these substances are very much lower than those of NO_x or SO_2, so much lower in fact that the proportion of these substances in the overall impact is less than 1 %.

ACSR 410mm2 (1m) toxicity to human－impact assessment					
	Item	**Quantity**	**Unit**	**Characterisation factor**	**Category indicators**
emission to air	As	2.64E-09	kg	4.70E+03	1.24E-05
	Cd	1.32E-10	kg	5.80E+02	7.67E-08
	CO	1.00E-02	kg	1.20E-02	1.20E-04
	Cr	2.64E-09	kg	6.70E+00	1.77E-08
	Hg	2.64E-09	kg	1.20E+02	3.17E-07
	Ni	1.19E-07	kg	4.70E+02	5.59E-05
	NOx	4.17E-02	kg	7.80E-01	3.25E-02
	Pb	7.93E-09	kg	1.60E+02	1.27E-06
	SO2	5.51E-02	kg	1.20E+00	6.62E-02
	V	6.61E-08	kg	1.20E+02	7.93E-06
	Zn	1.32E-08	kg	3.30E-02	4.36E-10
				Total	9.89E-02

Table 23: Impact on toxicity to human

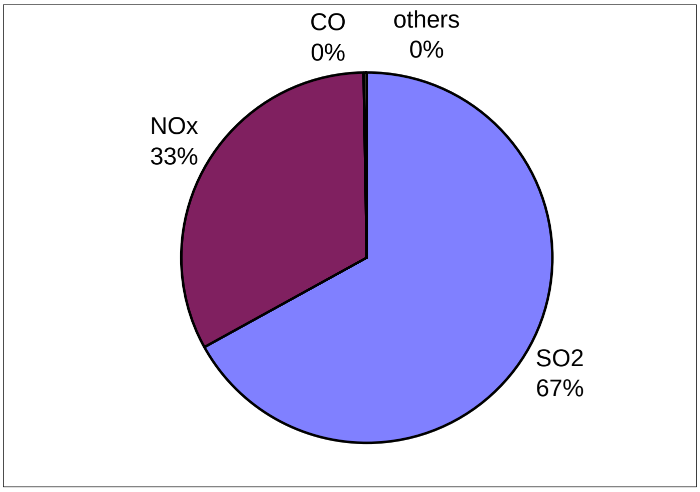


Figure 36: Impact on toxicity to humans

7.3.2.6 Solid wastes

Table 24 and ***Figure 37*** indicate the results of analysis. Red mud and other unspecified solid wastes are produced mainly in the manufacturing process of aluminum ingots, and slag is produced in the production of steel ingots. As the characterisation factors simply consider weight, they are all 1.0.

ACSR410mm2 (1m) solid waste－impact assessment

	Item	Quantity	Unit	Characterization factor	Category indicators
solid waste	CaSO4・2H2O	4.87E-05	kg	1.00E+00	4.87E-05
	red mud	2.78E+00	kg	1.00E+00	2.78E+00
	slag	1.54E-01	kg	1.00E+00	1.54E-01
	disposed PP	2.45E-05	kg	1.00E+00	2.45E-05
	unidentified solid	3.49E-01	kg	1.00E+00	3.49E-01
				total	3.29E+00

Table 24: Impact on solid waste

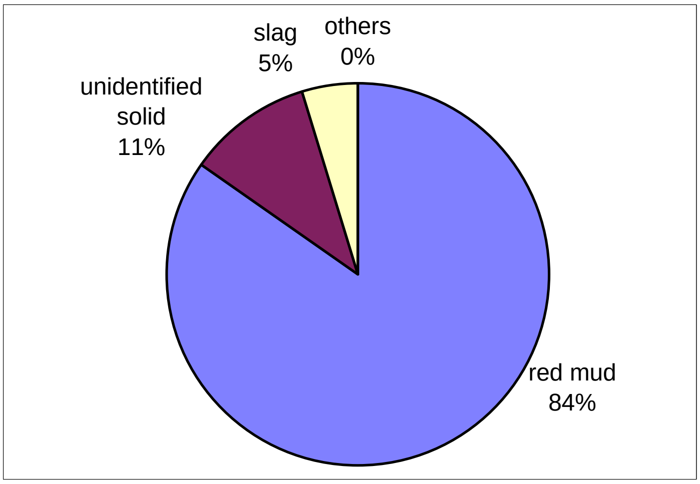


Figure 37: Impact on solid waste

7.3.3 Impact of recycling processes

Considering recycling processes as described in **7.1.3.3 System boundaries**, **Figure 38** shows the effect of the recycling processes. Since the amount of natural resource and emissions into the air is largely reduced (as stated in **7.3.1.3 Effect of recycling processes**) by the introduction of recycling procedures, in all of the impact categories, impact on the environment is also largely reduced in the recycling case.

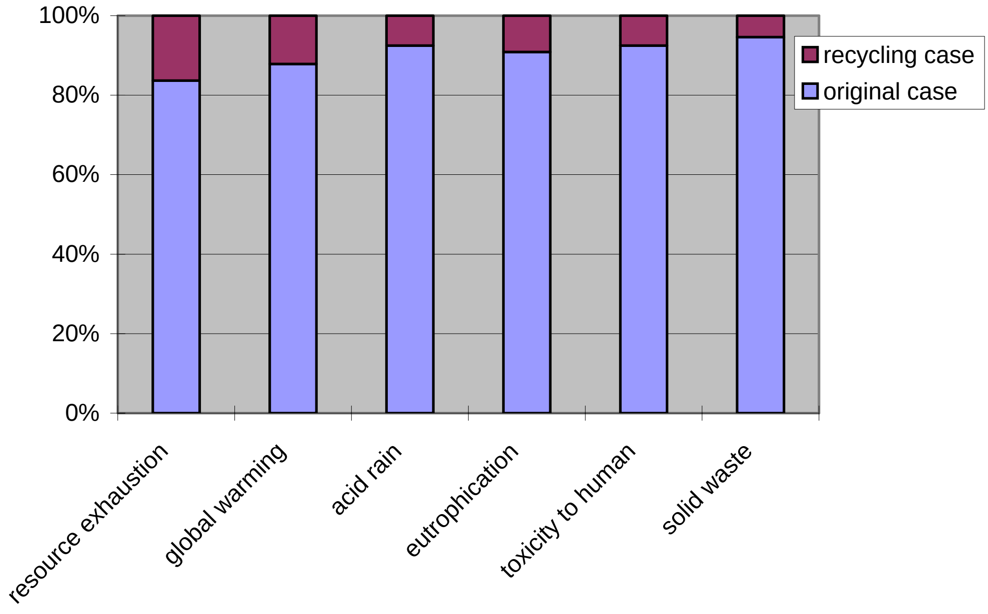


Figure 38: Comparison between original case and recycling case

7.3.4 Comparison of impact assessment in manufacturing and in operation

The environmental impact of ACSR 410 mm^2 during the manufacturing process and during operation is compared under the following conditions:

7.3.4.1 Presumption of a loading rate

Since the loading rate has a great impact on the transmission losses, two alternative approaches have been adopted to estimate the rate.

One approach is to examine the actual maximum peak load for each transmission line in a certain power system. In this case, 163 transmission lines (total continuous transmission capacity is around 14,000MW) were examined and the loading rate is defined as

Loading rate = Maximum peak load (MW) / Continuous transmission capacity (MW) x 100 (%) .

In this case, the result is 34.1%

Another approach is to presume that transmission lines should be uprated after 25 years use because of capacity shortage. Knowing the annual electric power demand over 25 years, the average loading rate over 25 years can be calculated. From the graph shown below the result is 49.2%. See ***Figure 39.***

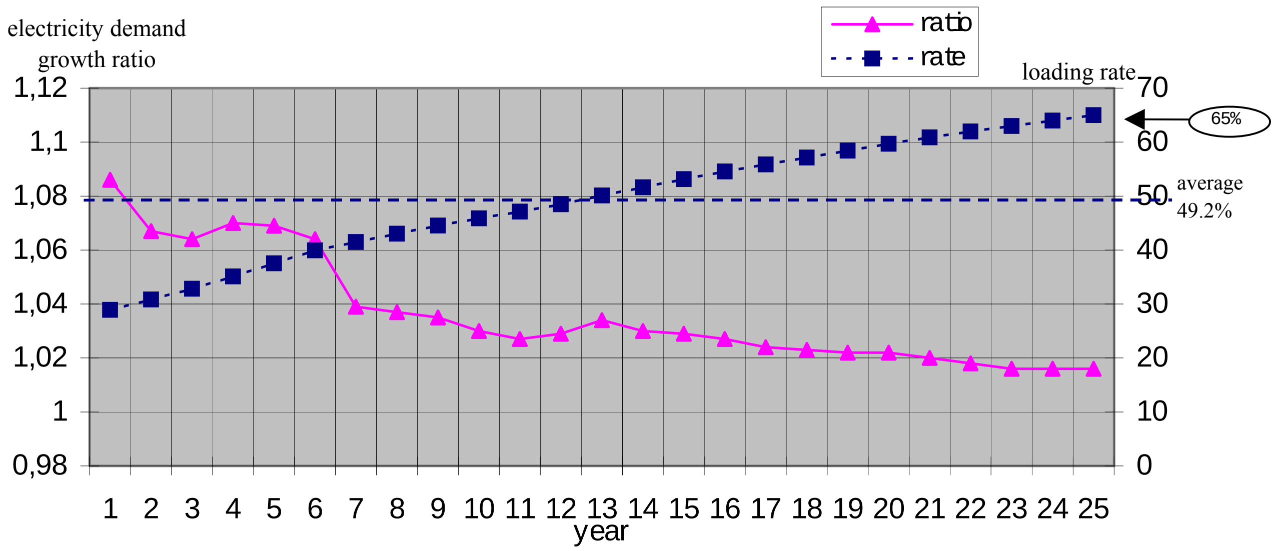


Figure 39: Relationship between loading rate and electricity demand growth ratio

In the above, the operating load capacity limit was set at 65% of the continuous transmission capacity because the continuous operating load capacity limit of the two circuits of the double circuit transmission line is an overload current rating for one circuit, considering single circuit faults on the line. The value is usually about 130% of the continuous transmission capacity for one circuit.

To convert these results to an annual average base, they should be multiplied by a load factor of 60%. The results come to about 20% to 30%. ((34.1% to 49.2%) x 60%)

7.3.4.2 Calculation for the conductor in operation

To estimate the transmission losses of the conductor in operation, calculations are carried out using the following equation:

$$\text{Loss} = 3 \cdot I^2 \cdot R$$

Where "R" indicates the ACSR 410 mm^2 resistance of 0.0702 Ω/km.

"I" is estimated using a 30% loading of the continuous allowable current (830 A), for ACSR 410 mm^2.

When assuming that the conductor will be used for 25 years, the transmission loss over this life period can be estimated as follows:

Calculation case	**Current (A)**	**Period (hour)**	**Transmission loss kWh/km**	**Transmission loss kWh/m**
At 30% load	249	219,000	2,859,570	2,860

7.3.4.3 Calculation results

Table 25 and ***Figure 40*** show the calculation at 30% load. These results indicate that the environmental impact of the conductor during operation is greater than that of the manufacturing process. As all the environmental impact of the conductor during operation increases proportionally to the square of current, it is clear that environmental impact during operation is greater than that of the manufacturing process for transmission lines with a large power flow.

ACSR410mm2(1m)		**Category indicators**	
Impact category	**Characterization factor**	**Use 25 years 30% loading**	**Manufacturing**
Resource exhaustion	1.0E+12/(deposits)[kg]	1.2855144	0.1220608
Global warming	GWP (CO2=1) Eco95	406.2477	18.93691
Acid rain	AP (SO2=1)	0.5270634	0.08430316
Eutrophication	NP (PO4=1)	0.0324	0.005418435
Toxicity to human	HCA,HCW	0.6745323	0.09886123

Table 25: Impact on solid waste

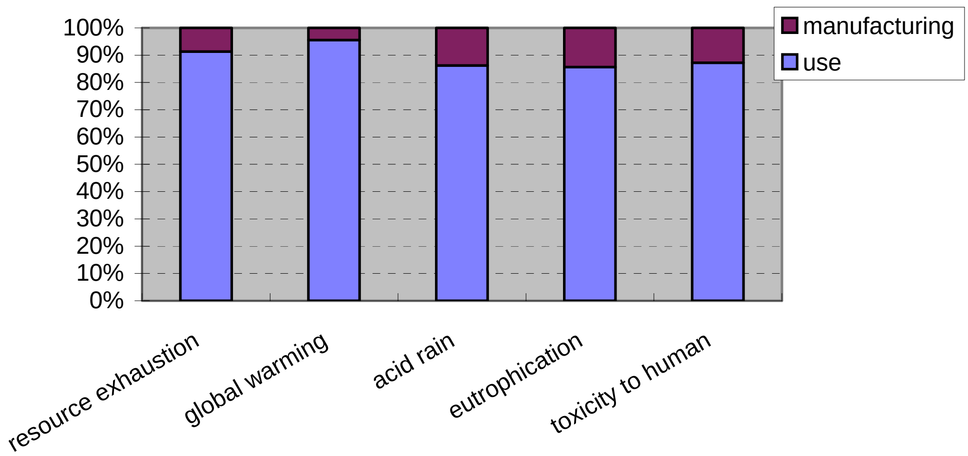


Figure 40: Comparison between operation and manufacturing

7.3.5 Conclusions and Recommendation

7.3.5.1 Conclusions

- In the manufacturing processes of ACSR, the manufacturing process of aluminum ingots has a dominant environmental impact.
- The environmental impact is not only related to ACSR manufacturing countries, but also related to outside countries in the world when the system boundaries include the extraction of resources and the material production.
- The recycling of conductor could reduce the environmental impact largely.

- The environmental impact of transmission losses is greater than that of the conductor manufacturing process (they have about ten times greater impact than that of the manufacturing phase).

7.3.5.2 Recommendation

To reduce environmental impacts, such as gas emission related impacts as well as resource exhaustion impact, it is strongly recommended that conductors should be recycled. It is commonly known that the energy required for recycled aluminum is about 3% of original aluminum production. The electrolysis process to extract alumina from bauxite for original aluminum production needs a large amount of electricity, while the aluminum recycling process basically consists of melting and molding processes, which need less energy than the electrolysis process.

Another way to reduce environmental impact is to reduce transmission losses. In this respect the development of low resistance conductor seems an effective way. Upgrading to a higher voltage power system may also seem to be effective; however a more comprehensive analysis of the whole power system would be needed to draw this conclusion.

7.4 Results of Analysis， Impact Assessment and Conclusions- Insulators (Porcelain Disc)

7.4.1 Results of inventory analysis

7.4.1.1 Analysing results by each process (Recycling processes are not considered)

Table 26 and ***Figures 41*** and ***42*** show the results of the analysis. These results indicate that energy resources (oil and coal) are mainly consumed in the insulator manufacturing processes (See ***Figure 41***). In this study, the process of “material manufacturing” is defined as the process, of raw material acquisition and material manufacturing before the insulator manufacturing processes, such as forming, glazing, or firing, for porcelain insulators are included. This trend is also shown in ***Figure 42*** (Emissions to air), reflecting the fact that emissions to air are mostly caused by fossil fuel combustion.

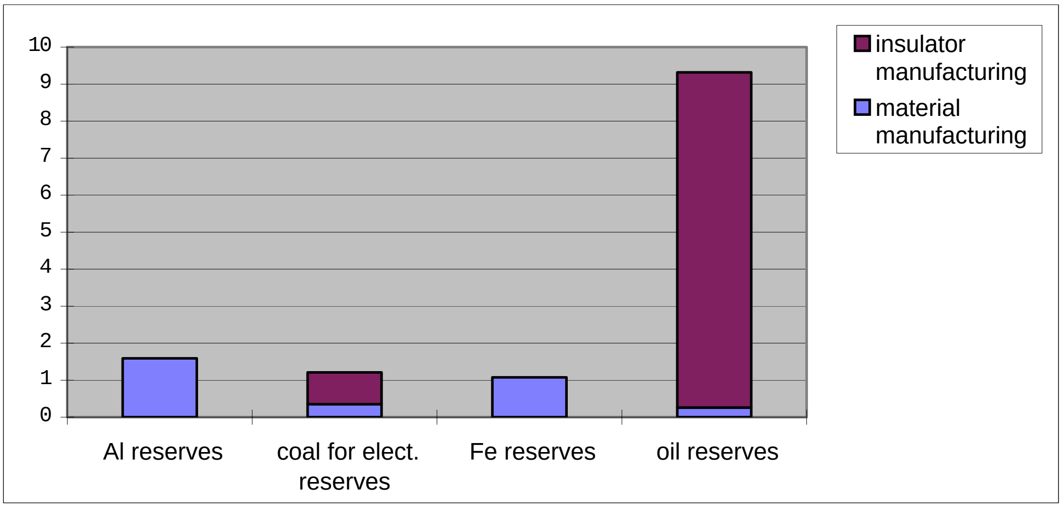
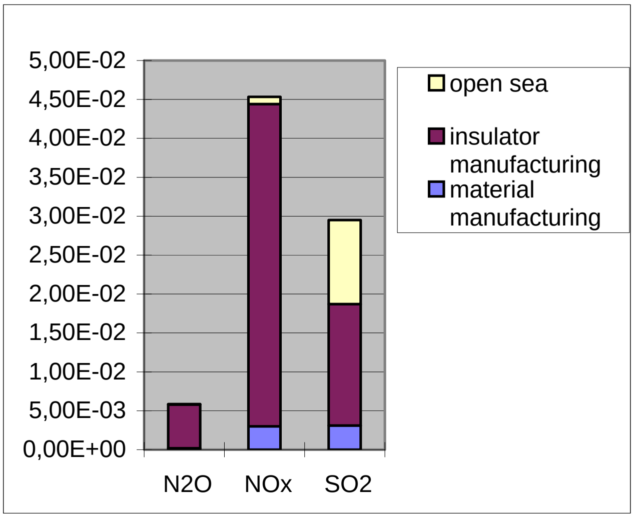


Figure 41: Inventory analysis of resource exhaustion in kg

(kg) (kg)



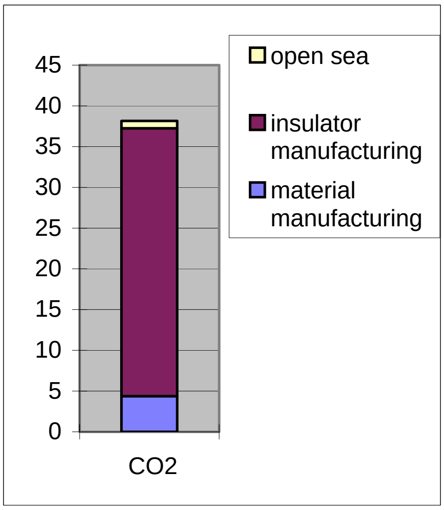


Figure 42: Inventory analysis of air pollution in kg

Insulator Porcelain 5 Discs - Inventory Result				**Results of Inventory Analysis *1**			
	No	**item**	**unit**	**total**	**material manufacturing**	**insulator manufacturing**	**open sea**
raw material [resource exhaustion]	1	Al reserves	kg	1.59	1.59		
	2	coal for coke reserves	kg	0.9091	0.9091		
	3	coal for elect. reserves	kg	1.2073	0.3481	0.8593	
	4	Fe reserves	kg	1.0771	1.0771		
	5	LNG reserves kg	kg	0.6136	0.0588	0.5548	
	6	Mn reserves	kg	0.0069	0.0069		
	7	oil reserves	kg	9.3191	0.2612	9.0579	
	8	Pb reserves	kg	0.0367	0.0367		
	9	U reserves	kg	6.52E-05	7.18E-06	5.81E-05	
	10	Zn reserves	kg	0.3096	0.3096		
emission to air	1	CH4	kg	1.74E-04	1.88E-05	1.55E-04	
	2	CO2	kg	38.1474	4.3821	32.877	0.8883
	3	N2O	kg	0.0058	1.95E-04	5.60E-03	6.13E-05
	4	NOx	kg	0.0453	3.00E-03	4.14E-02	9.31E-04
	5	SO2	kg	0.0294	3.10E-03	1.56E-02	0.0108
	6	CxHy	kg	3.40E-03	1.09E-04	3.20E-03	0.0000807
	7	dust	kg	3.60E-03	4.75E-04	2.60E-03	0.000513
	8	NMVOC	kg	0.000341	3.68E-05	3.04E-04	
	9	As	kg	3.59E-08	3.88E-09	3.20E-08	
	10	Cd	kg	1.80E-09	1.94E-10	1.60E-09	
	11	CO	kg	6.20E-03	8.95E-04	5.20E-03	1.42E-04
	12	Cr	kg	3.59E-08	3.88E-09	3.20E-08	
	13	Hg	kg	3.59E-08	3.88E-09	3.20E-08	
	14	Ni	kg	1.62E-06	1.74E-07	1.44E-06	
	15	Pb	kg	1.08E-07	1.16E-08	9.61E-08	
	16	V	kg	8.98E-07	9.69E-08	8.01E-07	
	17	Zn	kg	1.80E-07	1.94E-08	1.60E-07	

Table 26: Result of inventory analysis

: graphed see Figure 41 and 42

*1 Open sea: When intermediate products or materials are imported from abroad, gas from heavy oil combustion of marine transportation is classified into "open sea".

7.4.1.2 Results of domestic and oversea analysis (Recycling processes are not considered)

Table 27 and ***Figures 43*** and ***44*** show inland and overseas comparisons of inventory analysis. The results indicate that overseas account for the most part of the resource consumption (See ***Figure 43***). On the other hand, domestic has a much greater of the results of air pollution as shown in ***Figure 44***. This means that the insulator manufacturing processes which are dealt with domestically, have more impact on this area.

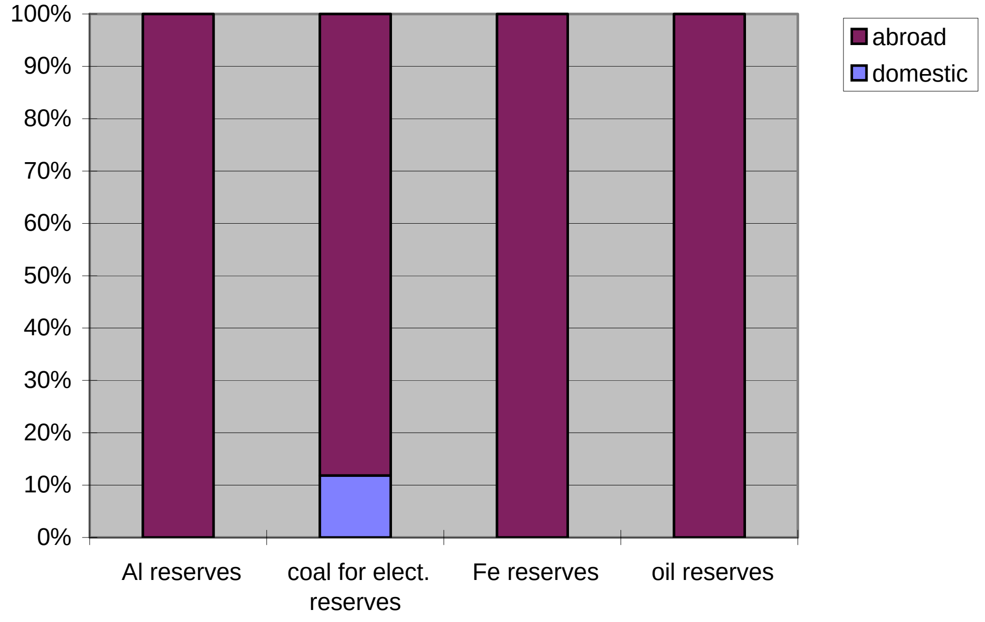


Figure 43: Resource exhaustion between domestic and overseas

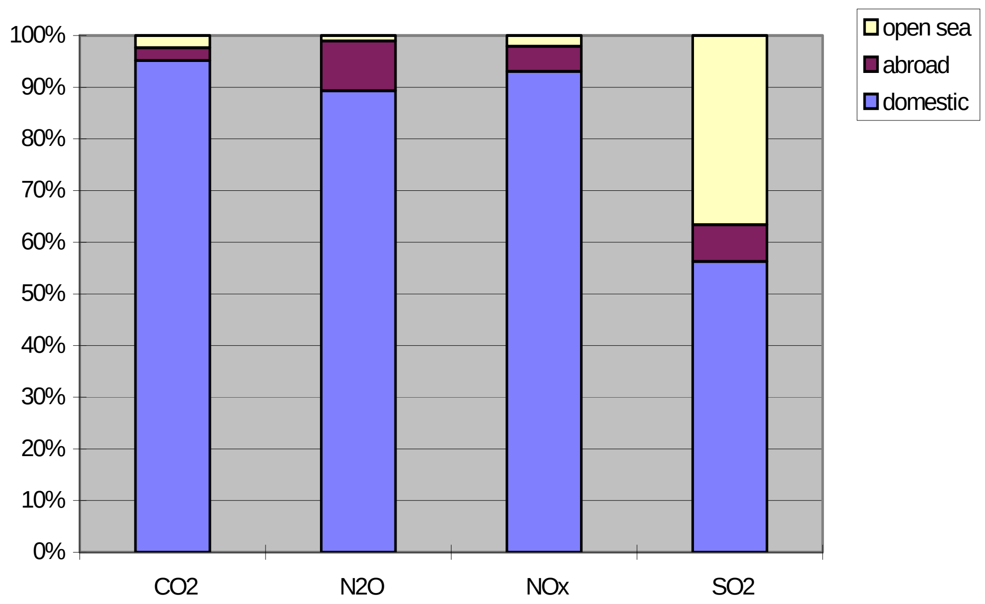


Figure 44: Air pollution between domestic and overseas

Insulator Porcelain 5 Discs - inventory result Porcelain (region)							
	No	**item**	**unit**	**total**	**domestic**	**abroad**	**open sea**
raw material [resource exhaustion]	1	Al reserves	kg	1.59		1.59	
	2	coal for coke reserves	kg	0.9091		0.9091	
	3	coal for elect. reserves	kg	1.2073	0.143	1.0644	
	4	Fe reserves	kg	1.0771		1.0771	
	5	LNG reserves kg	kg	0.6136	2.29E-04	0.6133	
	6	Mn reserves	kg	0.0069		0.0069	
	7	oil reserves	kg	9.3191	2.00E-04	9.3189	
	8	Pb reserves	kg	0.0367		0.0367	
	9	U reserves	kg	6.52E-05	6.51E-05	1.52E-07	
	10	Zn reserves	kg	0.3096	0.0384	0.2712	
emission to air	1	CH4	kg	1.74E-04	1.74E-04		
	2	CO2	kg	38.1474	36.3054	0.9536	0.8883
	3	N2O	kg	0.0058	5.20E-03	0.00056	6.13E-05
	4	NOx	kg	0.0453	0.0422	0.0022	9.31E-04
	5	SO2	kg	0.0294	1.66E-02	0.0021	0.0108
	6	CxHy	kg	3.40E-03	3.30E-03	0.000096	0.0000807
	7	dust	kg	3.60E-03	2.90E-03	0.000193	0.000513
	8	NMVOC	kg	0.000341	3.41E-04		
	9	As	kg	3.59E-08	3.59E-08		
	10	Cd	kg	1.80E-09	1.80E-09		
	11	CO	kg	6.20E-03	5.40E-03	0.0006	0.000142
	12	Cr	kg	3.59E-08	3.59E-08		
	13	Hg	kg	3.59E-08	3.59E-08		
	14	Ni	kg	1.62E-06	1.62E-06		
	15	Pb	kg	1.08E-07	1.08E-07		
	16	V	kg	8.98E-07	8.98E-07		
	17	Zn	kg	1.80E-07	1.80E-07		

Table 27: Comparison between domestic and overseas

7.4.2 Impact assessment results (Recycling processes are not considered)

7.4.2.1 Resource exhaustion

Table 28 and ***Figure 45*** show the results of the analysis. In **Table 28**, although the quantity of coal, heavy oil and aluminum is larger than that of zinc, the impact on resource exhaustion is the greatest for zinc, followed by lead. This is caused by the characterisation factors used in the study.

Insulator Porcelain Disc 5pieces resource exhaustion－impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
raw material [resource exhaustion]	Al reserves	1.59E+00	kg	2.94E-02	4.68E-02
	coal for coke reserves	9.09E-01	kg	1.93E-03	1.75E-03
	coal for elect. reserves	1.21E+00	kg	1.93E-03	2.33E-03
	Fe reserves	1.08E+00	kg	1.32E-02	1.42E-02
	LNG reserves kg	6.14E-01	kg	9.70E-06	5.95E-06
	Mn reserves	6.86E-03	kg	2.00E-01	1.37E-03
	oil reserves	9.32E+00	kg	7.26E-03	6.77E-02
	Pb reserves	3.67E-02	kg	7.14E+00	2.62E-01
	U reserves	6.52E-05	kg	2.22E+02	1.45E-02
	Zn reserves	3.10E-01	kg	2.27E+00	7.04E-01
				total	1.11E+00

Table 28: Impact on resource exhaustion

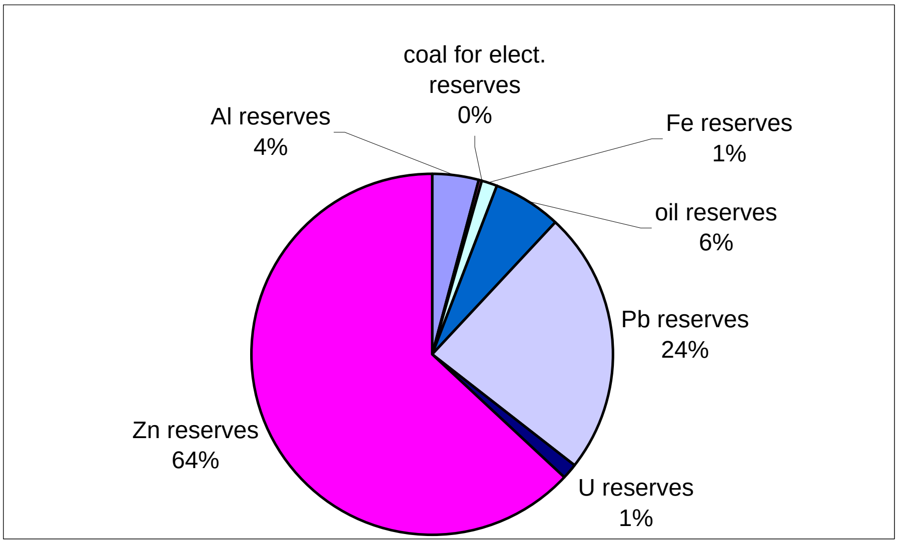


Figure 45: Impact on resource exhaustion

7.4.2.2 Global warming

Table 29 and ***Figure 46*** show the results of analysis. The CO_2 emissions are remarkably large in comparison with that of other gases and have a dominant impact on global warming.

Insulator Porcelain 5 discs global warming－impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
emission to air	CH4	1.74E-04	kg	1.10E+01	1.92E-03
	CO2	3.81E+01	kg	1.00E+00	3.81E+01
	N2O	5.84E-03	kg	2.70E+02	1.58E+00
				total	3.97E+01

Table 29: Impact on lobal warming

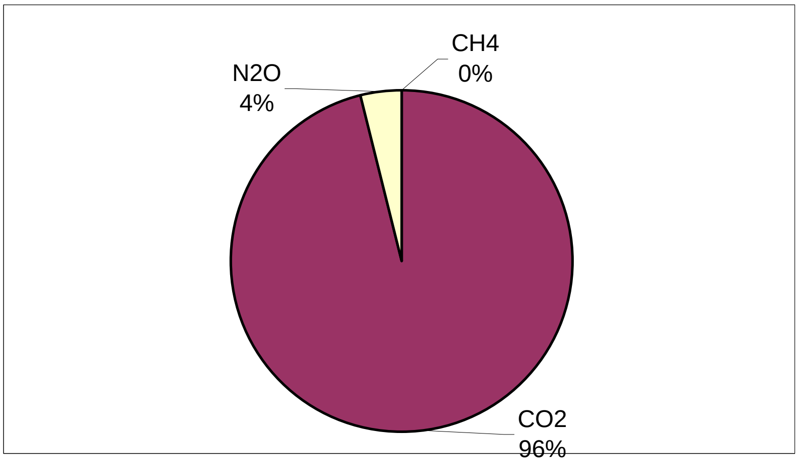


Figure 46: Impact on global warming

7.4.2.3 Acid rain

The results of the analysis are shown in **Table 30** and ***Figure 47***. Emissions having some connection with acid rain are only NO_x and SO_2 in this study, and these two compounds are totally responsible for the environmental impact.

Insulator Porcelain Disc 5pieces acid rain－impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
emission to air	NOx	4.53E-02	kg	7.00E-01	3.17E-02
	SO2	2.94E-02	kg	1.00E+00	2.94E-02
				total	6.12E-02

Table 30: Impact on acid rain

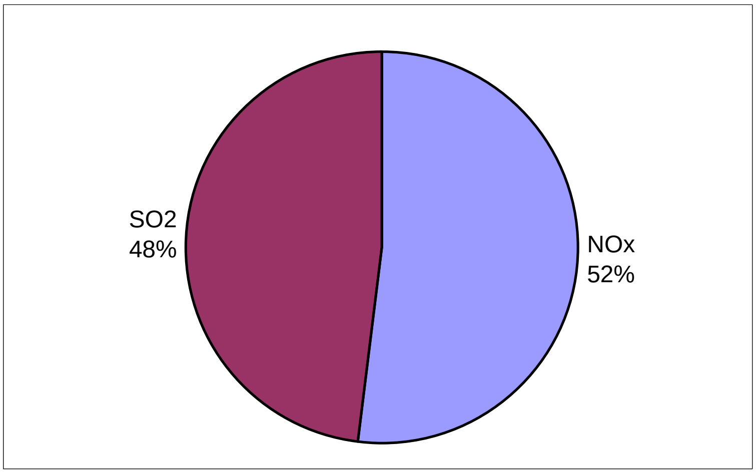


Figure 47: Impact on acid rain

7.4.2.4 Eutrophication of lakes and marshes

Table 31 suggests that NO_x is the only emission that relates to the eutrophication of lakes and marshes.

Insulator Porcelain 5 Discs eutrophication－impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
emission to air	NOx	4.53E-02	kg	1.30E-01	5.89E-03
				total	5.89E-03

Table 31: Impact on eutrophication

7.4.2.5 Toxicity to human body

Table 32 and ***Figure 48*** show the results of the analysis. While the graphs indicate that NO_x and SO_2 are the main emissions relevant to such toxicity, the tables suggest the existence of several other substances that have some impact on this category. The emissions of these substances are considerably lower than those of NO_x or SO_2, therefore the proportion of these substances in the overall impact is 2 % or less.

Insulator Porcelain 5 Discs Toxicity to human－ impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
emission to air	As	3.59E-08	kg	4.70E+03	1.69E-04
	Cd	1.80E-09	kg	5.80E+02	1.04E-06
	CO	6.19E-03	kg	1.20E-02	7.43E-05
	Cr	3.59E-08	kg	6.70E+00	2.41E-07
	Hg	3.59E-08	kg	1.20E+02	4.31E-06
	Ni	1.62E-06	kg	4.70E+02	7.59E-04
	NOx	4.53E-02	kg	7.80E-01	3.54E-02
	Pb	1.08E-07	kg	1.60E+02	1.72E-05
	SO2	2.94E-02	kg	1.20E+00	3.53E-02
	V	8.98E-07	kg	1.20E+02	1.08E-04
	Zn	1.80E-07	kg	3.30E-02	5.92E-09
				total	7.18E-02

Table 32: Impact on toxicity to human

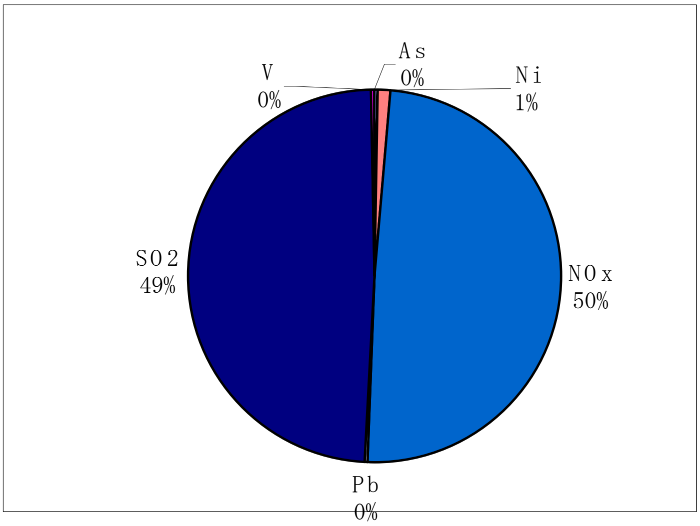


Figure 48: Impact on toxicity to human

7.4.2.6 Solid wastes

Table 33 indicates the results of analysis. Slag is the only substance in this category. Slag is produced in the production of steel ingots, zinc and silicon metal. As the category indicator simply considers weight, it is 1.0.

Insulator Porcelain Disc 5pieces solidwaste－ impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
solid waste	slag	1.04E+00	kg	1.00E+00	1.04E+00
				total	1.04E+00

Table 33: Impact on solid waste

7.4.3 Conclusions and Recommendation

7.4.3.1 Conclusions

More energy resources are consumed in the insulator manufacturing processes of insulators than in the raw material manufacturing process and that results in more domestic emission of gases (such as CO_2, NO_x, SO_2) to air as well as an increase in the environmental impact.

7.4.3.2 Recommendations

Although a small percentage of removed insulators are experimentally recycled as construction materials, a porcelain insulator recycling system is not fully established. Knowing that more energy is consumed in the insulator manufacturing processes of insulators than in the raw material manufacturing processes, establishment of the reuse of removed insulators as value added materials is desirable since material production itself for insulator production is not so energy consuming and it seems important to effectively reuse insulators which have already consumed energy in their manufacturing process.

Another approach to reduce environmental impacts might be to extend the function as insulators as long as possible. In this respect development of efficient and reliable diagnostic methods as well as life span extension technology is required.

8. OVERHEAD LINE LCA STUDIES

8.1 Life Cycle Assessment (LCA) of 154kV Overhead Transmission Line (Japan)

8.1.1 Introduction

Specific calculations of LCA were performed concerning several limited processes for an OHL model based on the procedure specified in the ISO 14040 series. An actual analysis was carried out using the LCA software "JEMAI-LCA" which was developed by the Japan Environmental Management Association for Industry (JEMAI). This section covers the LCA for a 154kV overhead transmission line model in Japan, taking the effects of material and fuel import from abroad into consideration.

8.1.2 LCA phases (ISO 14040)

The analysis is carried out based on the following three basic phases.

- Definition of goal and scope
- Inventory analysis
- Impact assessment

A discussion of the results is included at the end of this section for reference.

8.1.3 Methodology

8.1.3.1 Definition of goal and scope

Goal of the study

This LCA is performed to:

- Give an example of how to develop an appropriate LCA methodology for power transmission lines.
- Make trial calculations of the various environmental burdens on the life cycle of a 154kV transmission line model.
- Roughly assess the environmental impact of the model.

The intended audience was as follows:

- CIGRE SCB2 members
- General consumers (customers of electric power companies)
- People in the communities of construction sites for power transmission lines

Function and functional unit

The function of overhead transmission lines in the execution of this LCA is to transmit electricity, and it might seem to be appropriate to use electric current unit (A) as the functional unit. However, in the consideration of each unit process for constructing the 154kV transmission line, the product unit of a 154kV transmission line should be used as the functional unit. For a possible future study, the relationship between the transmission line model studied and the transmission capacity for the model, could be determined so that the results could be converted (from (transmission line) to (A)) at the impact assessment phase or other phases.

In this case study, one 154kV transmission line model is adopted as a functional unit. See Attachment-1 (at the end of this section) for the outline of the model.

System boundaries

The processes, which will be studied in this study, are shown within the broken line below:

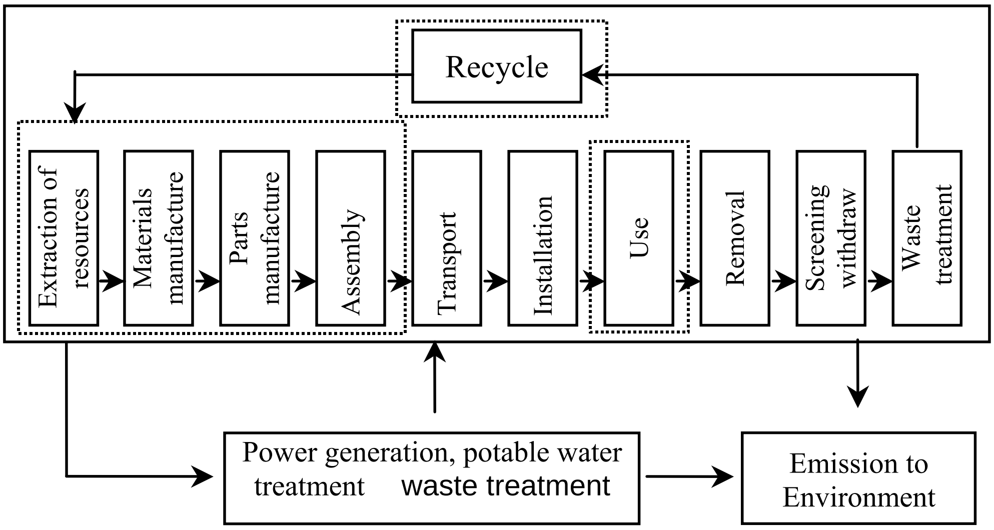


Figure 49: The processes studied in this assessment, as shown

Recycling processes are considered in LCA for the lattice tower and conductor. For both of the two components, it is presumed that 90% of the components are recycled except the foundation of the tower. “Use process” is considered in LCA for conductor as a form of transmission energy loss.

Data categories

The following data are input or output in the above processes:

- Input of energy and raw materials
- Products (main product, intermediate products, coproducts)
- Emissions
  - Emission to air (CO2, NOx, SOx, etc.)
  - Emission to land (solid wastes, etc.)

8.1.3.2 Inventory analysis

Analysis method

“Process analysis” is applied to the inventory analysis.

Applicable system category

In drawing up a process chart to execute the LCA, various secondary flows are produced along with a main flow. The following are the basic flows to be considered:

[Secondary flows and how to deal with them]

- ”Capital goods” of factories, power plants and other facilities --- not included in principle.
- The processes of “coproducts” --- when there is a co-product that may generate economic value profits and is not simply disposed of as waste, the environmental burden in the manufacturing process is divided proportionally between it and the main product.
- “Packing materials” used for transportation --- packing materials are not included in the system except for the wooden drum for ACSR and wooden container for insulators. (Since other packing materials are not so voluminous that the influence of them could be negligible.)
- The manufacturing process of “secondary raw materials” with a small component ratio --- not included in principle.
- Human labour --- not included in principle.

Inventory list

The main inventories included in the calculation are shown below.

- Resource exhaustion
  (Iron, Aluminum, Manganese, Zinc, Lead, Oil, Coal, Natural gas, Uranium)
- Air pollution
  (CO_2, NO_x, SO_2, etc.)

For the results, please see **8.1.4 Results**.

Data collection procedures

The input and output data in each process analyzed which are particular to overhead transmission lines is collected using the process analysis method. For processes that are not particular to transmission lines but are widely used in various industries, the basic database of the LCA execution software is used.

[Processes particular to overhead transmission lines in this study]

- Parts manufacturing for lattice tower (eg: Steel angle member, plate, and bolt manufacturing)
- Conductor manufacturing (eg: Aluminum strands, steel strands, and stranded wires)
- Insulator manufacturing (eg: Material crushing, forming, glazing, firing, and Assembling)
- Use (Operation, transmission losses)

Allocation procedures of co-products

With regard to coproducts, the environmental burden in the manufacturing process of co-products is proportionally allocated.

Allocation procedures for recycling processes

The environmental burdens related to recycling are considered in this study. The environmental burdens of the recycled products are subtracted from the original environmental burden amount, which does not include recycling processes.

Allocation procedure to each country

Japan imports a large amount of raw materials from overseas. All the electric energy, inputs of raw materials and outputs to the atmosphere, water and ground, which are related to the imported material, are added up respectively through its upstream processes and distributed to the importing countries according to the ratio settled on for the imported material.

For example, if Japan imports 70% of aluminum ingots from country A and the remaining 30% from country B, all the energy consumption, resourse exhaustion, and emission related to the aluminum ingot production processes (from bauxite mining to aluminum refining) are distributed between the two countries according to the proportion of 70 : 30.

Marine transportation of raw materials or intermediate products

Transportation of raw materials or intermediate products by sea is taken into consideration as a form of gas (CO_2, NO_x, SO_2, etc.) emission to the air. These emissions caused by heavy oil combustion or LNG combustion of marine transportation is classified into “open sea” in inventory analysis.

Power generation process

Electricity used in the processes is converted to inventory items (inputs of raw materials and outputs to the atmosphere). In this procedure, power generation efficiency and power generation type adopted in each country is taken into account. The procedure is same as that for the LCA studies, OHL Components. Please refer to 7.1.4.9 for details.

8.1.3.3 Impact assessment

Relationship between inventory data and the impact category of environmental burdens

The following are the impact categories considered in this LCA.

- Resource exhaustion
- Global warming
- Acid rain
- Eutrophication of lakes and marshes
- Toxicity to human body
- Solid wastes

Category indicators for converting the data to the impact categories

The category indicators used to convert inventory data into the above impact categories are:

- Resource exhaustion → Inverse of total deposits in the world
- Global warming → Global Warming Potential (the IPCC 1992 report 100-year GWP)
- Acid rain → Acidification Potential: Leiden University Institute CML (CML Method)
- Eutrophication of lakes and marshes → Leiden University Institute CML (CML Method)
- Toxicity to human body → Leiden University Institute CML (CML Method)
- Solid wastes → Weight (kg)

IPCC: Intergovernmental Panel on Climate Change

Leiden University Institute CML (Center of Environmental Science)

Characterization factor CML potential (1992) by R. Heijungs

8.1.4 Results

8.1.4.1 154kV transmission line model without use and recycle processes

Results of inventory analysis

Analyzing results by each process

Table 34 and ***Figure 50*** and ***51*** show the results of the analysis. **Table 34** indicates that coal for coke reserves, which is used for pig iron production in the furnace, and Fe reserves are mainly consumed in the lattice tower manufacturing process. On the other hand, Al reserves, coal for electric reserves, and oil reserves are mainly consumed in the conductor manufacturing process. It reflects the fact that aluminum production from bauxite for conductor manufacturing requires a lot of electricity. In ***Figure 51*** (Emission to air), CO_2, N_2O, NOx, and SO_2 are exhausted mainly from conductor manufacturing. It also shows the large amount of electricity consumption (fossil fuel combustion) for aluminium production.

154kV transmission line - Inventory Result										
	No	item	unit	total	lattice tower	foundation	insulator	conductor	earth wire	open sea *1
raw material [resource exhaustion]	1	Al reserves	kg	2.74E+03			2.10E+01	2.72E+03		
	2	coal for coke reserves	kg	4.66E+03	3944.5164	13.3697	12	592.8466	97.706	
	3	coal for elect. reserves	kg	8.35E+03	9.58E+02	357.8471	15.9369	6990	31.6626	
	4	Fe reserves	kg	6337.2848	5390.1212		14.2179	799.6677	133.278	
	5	LNG reserves kg	kg	2318.9445	171.8552	4.3333	8.0992	2120	14.6568	
	6	Mn reserves	kg	4.04E+01	34.346		0.0906	5.0964	0.8494	
	7	oil reserves	kg	5701.3692	1347.2414	29.9364	123.0124	4180	21.179	
	8	Pb reserves	kg	33.2792	27.508		4.84E-01	4.53E+00	7.55E-01	
	9	U reserves		0.048735	0.017888	0.000512	8.61E-04	2.85E-02	9.74E-04	
	10	Zn reserves	kg	277.9846	232.3356		4.0863	35.6252	5.9375	
emission to air	1	CH4	kg	0.0803	0.0471	0.0014	0.0023	0.0269	0.0026	
	2	CO2	kg	5.99E+04	1.75E+04	2.33E+03	491.8196	3.80E+04	4.40E+02	1200
	3	N2O	kg	6.9158	1.5247	0.1456	0.0763	5.0986	0.0333	0.0373
	4	NOx	kg	100.7493	9.1436	2.3709	0.586	87.1192	0.2542	1.2754
	5	SO2	kg	135.081	6.5971	1.6937	0.2466	110.84	0.1967	15.5069
	6	As	kg	1.65E-05	9.70E-06	2.82E-07	4.74E-07	5.55E-06	5.34E-07	
	7	Cd	kg	8.27E-07	4.86E-07	1.41E-08	2.37E-08	2.77E-07	2.67E-08	
	8	CO	kg	24.888	2.6502	0.8934	0.0798	20.982	0.074	0.2086
	9	Cr	kg	1.65E-05	9.70E-06	2.82E-07	4.74E-07	5.55E-06	5.34E-07	
	10	Hg	kg	1.65E-05	9.70E-06	2.82E-07	4.74E-07	5.55E-06	5.34E-07	
	11	Ni	kg	7.45E-04	4.37E-04	1.27E-05	2.13E-05	2.50E-04	2.40E-05	
	12	Pb	kg	4.96E-05	2.91E-05	8.46E-07	1.42E-06	1.66E-05	1.60E-06	
	13	V	kg	4.14E-04	2.43E-04	7.05E-06	1.18E-05	1.39E-04	1.33E-05	
	14	Zn	kg	8.27E-05	4.86E-05	1.41E-06	2.37E-06	2.77E-05	2.67E-06	

: graphed see ***Figure 50*** and ***51***

*1 Open sea: When intermediate products or materials are imported from abroad, gas from heavy oil combustion of marine transportation is classified into "open sea".

Table 34

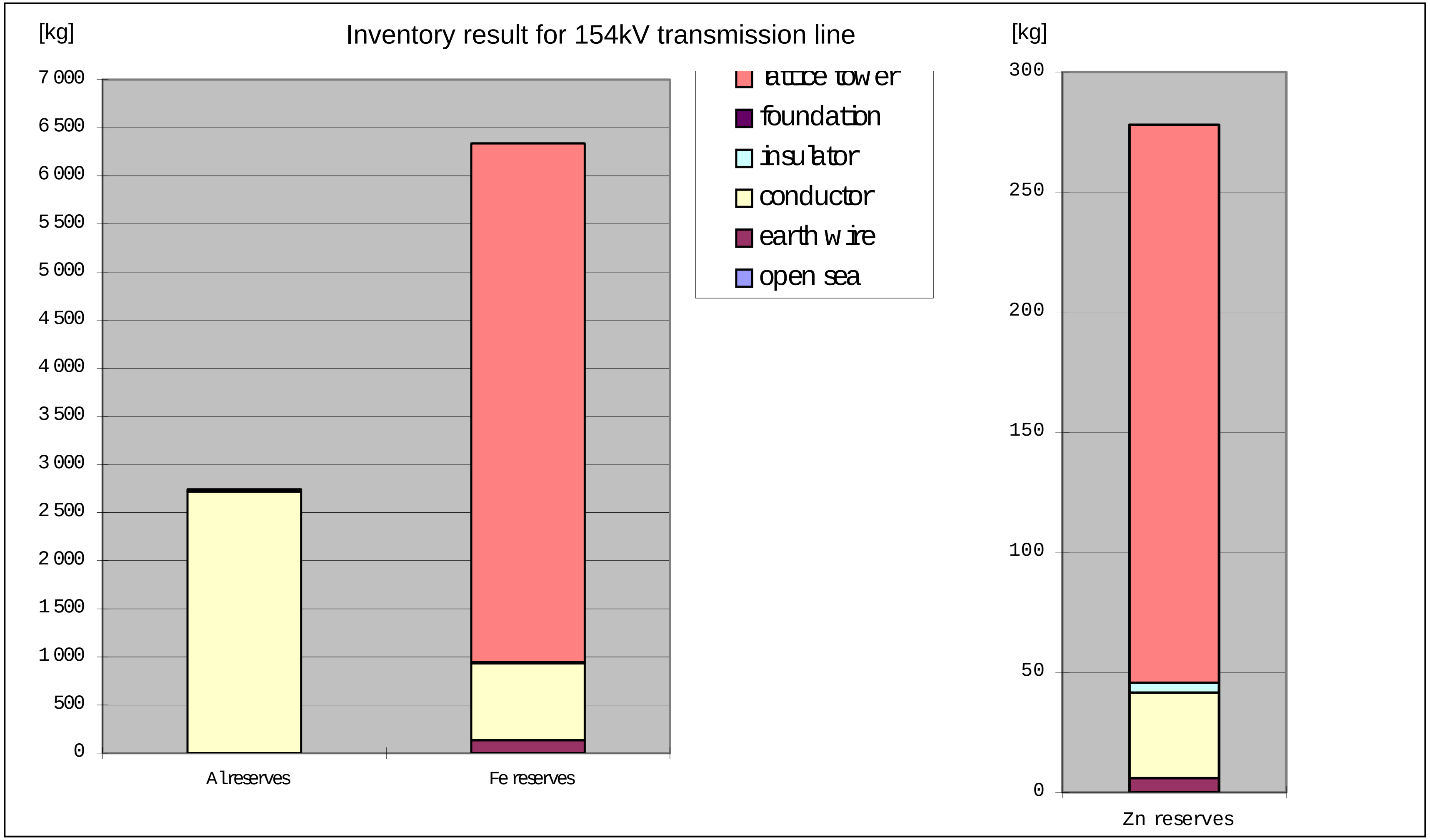


Figure 50: Resource Exhaustion

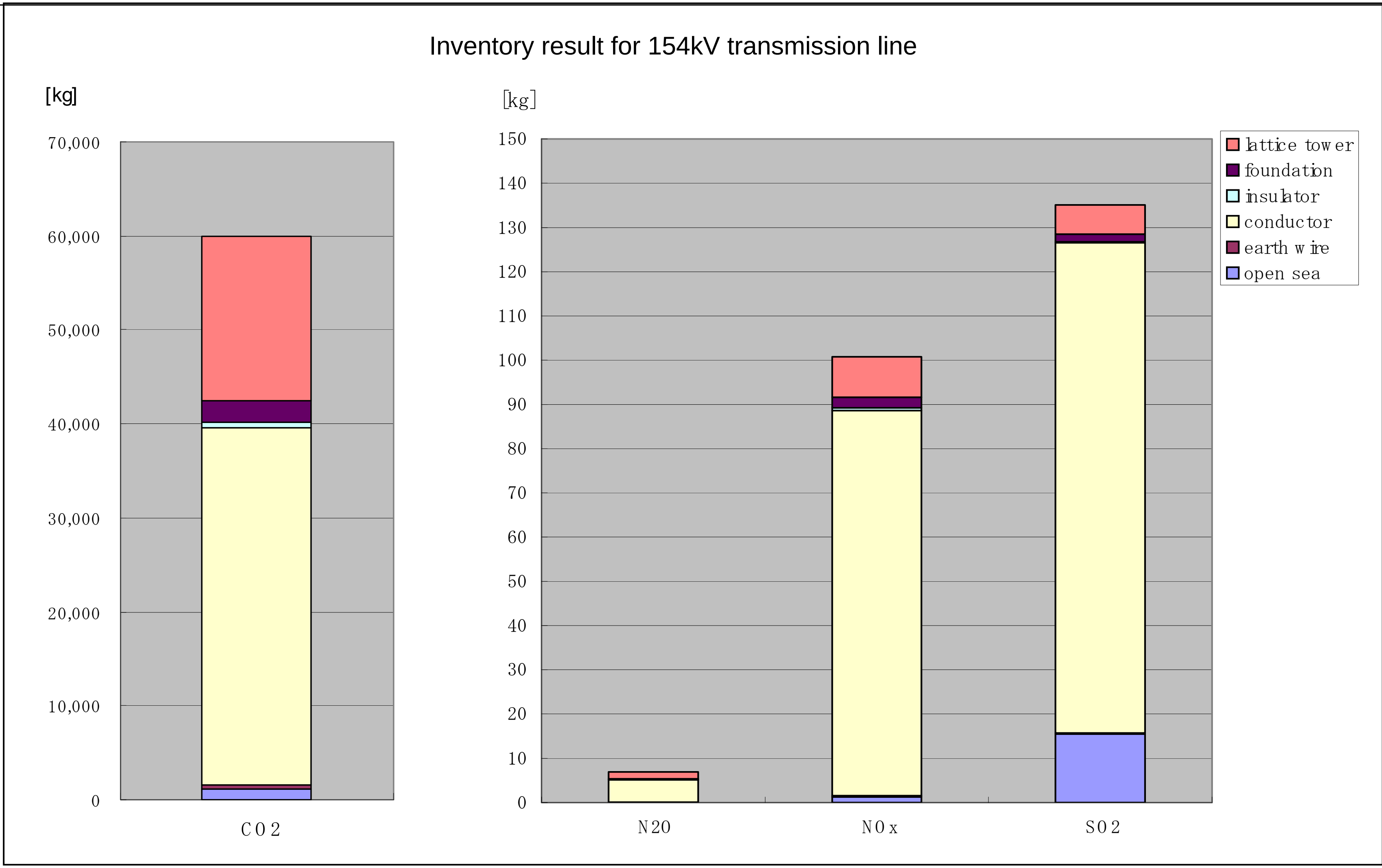


Figure 51: Emission to Air

Impact assessment results

Resource exhaustion

Tables 35 and **36** and ***Figures 52*** and ***53*** show the results of analysis. From ***Figure 52***, we can see that zinc and lead accounts for about 80% of total impact. Iron and aluminum, which are the main material for the transmission line model, have less impact than those of zinc and lead. It means characterisation factors for zinc and lead are much larger than those for iron and aluminum.

Zinc and lead are consumed in steel galvanization process, which is one of main processes for lattice steel tower manufacturing. Therefore in ***Figure 53***, lattice tower has the major impact on this category followed by conductor.

Global warming

Tables 37 and **38** and ***Figures 54*** and ***55*** show the results of the analysis. The CO_2 emissions are remarkably large in comparison with those of other gases and have a dominant impact on global warming. The main processes, which emit CO_2 are electricity production, use in the furnace of coke for pig iron production, and combustion of LPG for lattice steel tower production. The combustion of LPG has a relatively small impact compared to the other processes because of its limited volume.

Figure 54 shows that the conductor, which consumes a large amount of electricity in its aluminum production process, has the largest impact followed by lattice steel tower, which consumes electricity and coke in its production processes.

Acid rain

The results of the analysis are shown in **Tables 39** and **40** and ***Figures 56*** and ***57.*** Emissions having some connection with acid rain are only NO_x and SO_2 in this study, and these two compounds are totally responsible for the environmental impact.

Emissions of these gases are caused mainly by electricity production, which contribute to make the conductor having the largest impact in ***Figure 57***.

Eutrophication of lakes and marshes

Table 41 suggests that NO_x is the only emission that relates to the eutrophication of lakes and marshes. **Table 42** and ***Figure 58*** show that it has similar tendency to acid rain derived from the influence of the gas from electricity production.

Toxicity to human body

Table 43 and **44** and ***Figure 59*** and ***60*** show the results of the analysis. ***Figure 59*** indicates that NO_x and SO_2 are the main emissions relevant to toxicity to human body, having the same trend in ***Figure 60*** as Acid rain and Eutrophication. **Table 43** suggests the existence of several other substances that have some impact on this category. The emissions of these substances are lower than that of NO_x or SO_2, therefore the proportion of these substances in the overall impact is less than 1 %.

154kV transmission line resource exhaustion－impact assessment					
	item	quantity	unit	characterization factor	category indicators
raw material [resource exhaustion]	Al reserves	2.75E+03	kg	0.0294	80.7
	coal for coke reserves	4.66E+03	kg	1.93E-03	9.00E+00
	coal for elect. reserves	8.35E+03	kg	1.93E-03	1.61E+01
	Fe reserves	6.34E+03	kg	1.32E-02	8.35E+01
	LNG reserves kg	2.32E+03	kg	9.70E-06	2.25E-02
	Mn reserves	4.04E+01	kg	2.00E-01	8.08E+00
	oil reserves	5.70E+03	kg	7.26E-03	4.14E+01
	Pb reserves	3.33E+01	kg	7.14E+00	2.38E+02
	U reserves	4.87E-02	kg	2.22E+02	1.08E+01
	Zn reserves	2.78E+02	kg	2.27E+00	6.32E+02
				total	1.12E+03

Table 35

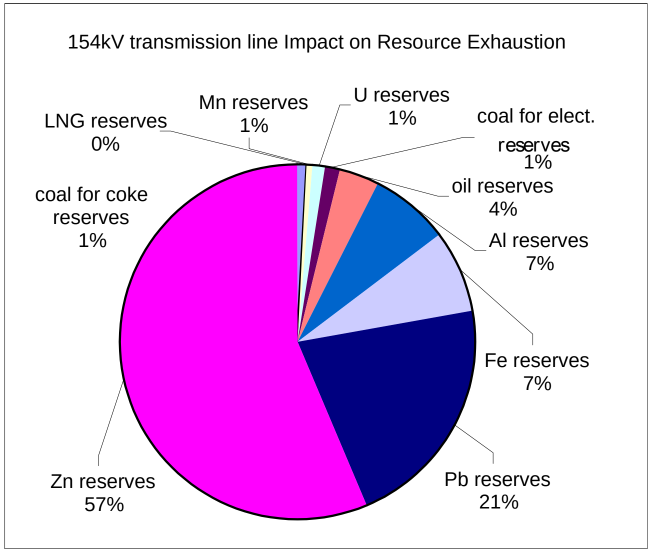


Figure 52

Category indicator for each component

impact category	category indicator	lattice tower	foundation	insulator	conductor	earth wire	SUM
resource exhaustion	Inverse of total deposits in the world	824.9525806	1.047419	14.652	256.2	22.346	1119.198

Table 36

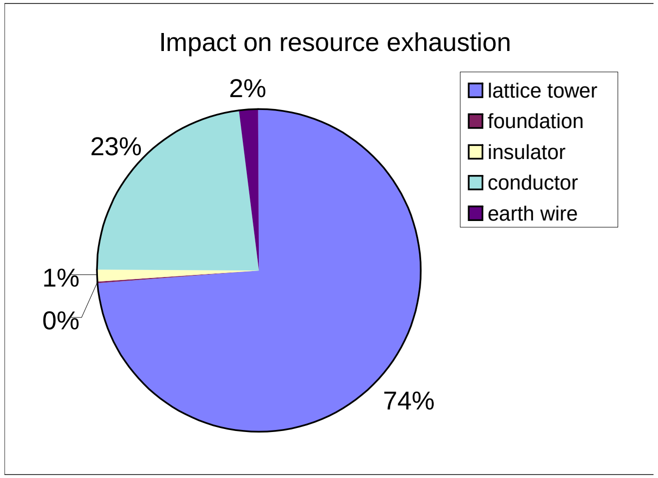


Figure 53

154kV transmission line global warming - impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
emission to air	CH4	8.02E-02	kg	1.10E+01	8.83E-01
	CO2	6.00E+04	kg	1.00E+00	6.00E+04
	N2O	6.92E+00	kg	2.70E+02	1.87E+03
				total	6.18E+04

Table 37

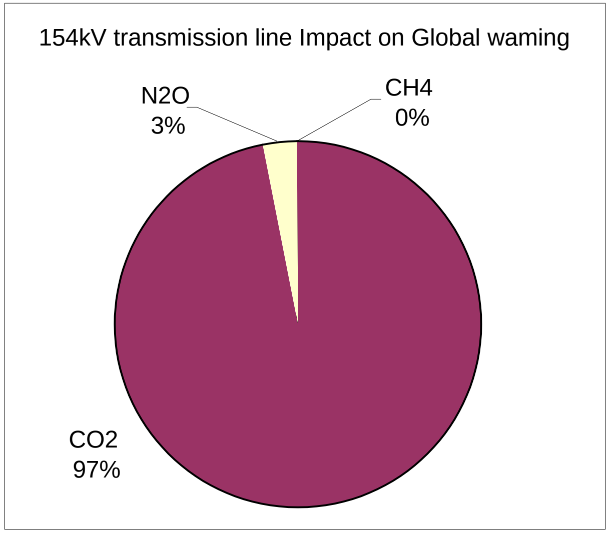


Figure 54

impact category	category indicator	lattice tower	foundation	insulator	conductor	earth wire	SUM
global warming	GWP	18713.27782	2386.722	524.04	39690	516.53	61830.57

Table 38: Category indicator for each component

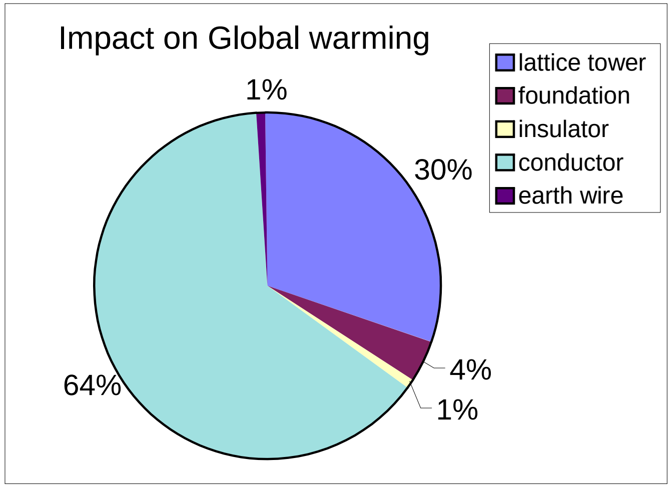


Figure 55

154kV transmission line acid rain - impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
emission to air	NOx	1.01E+02	kg	7.00E-01	7.05E+01
	SO2	1.35E+02	kg	1.00E+00	1.35E+02
				total	2.06E+02

Table 39

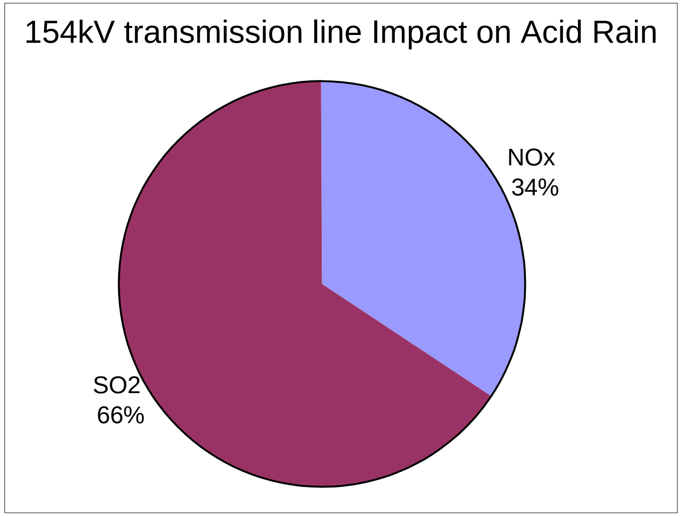


Figure 56

Category indicator for each component

impact category	category indicator	lattice tower	foundation	insulator	conductor	earth wire	SUM
acid rain	Acidification potential	23.66794666	3.532053	0.80784	177.03	0.56776	205.6056

Table 40

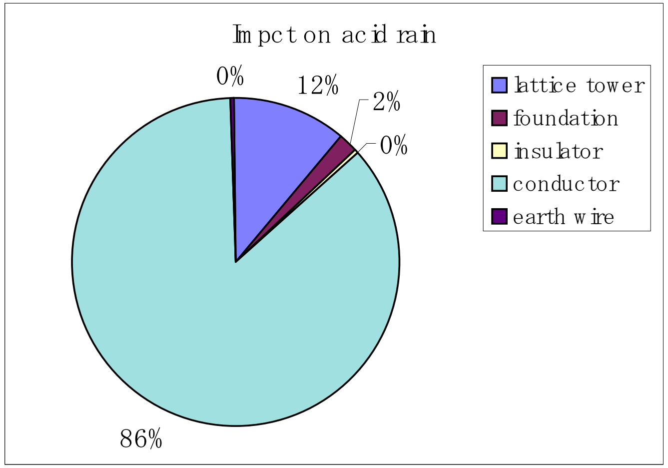


Figure 57

154kV transmission line eutrophication - impact assessment					
	item	quantity	unit	**characterization factor**	**category indicators**
emission to air	NOx	1.01E+02	kg	1.30E-01	1.31E+01
				total	1.31E+01

Table 41

impact category	category indicator	lattice tower	foundation	insulator	conductor	earth wire	SUM
eutrophication	ODP	1.289964232	0.310036	0.077748	11.382	0.037672	13.09742

Table 42: Category indicator for each component

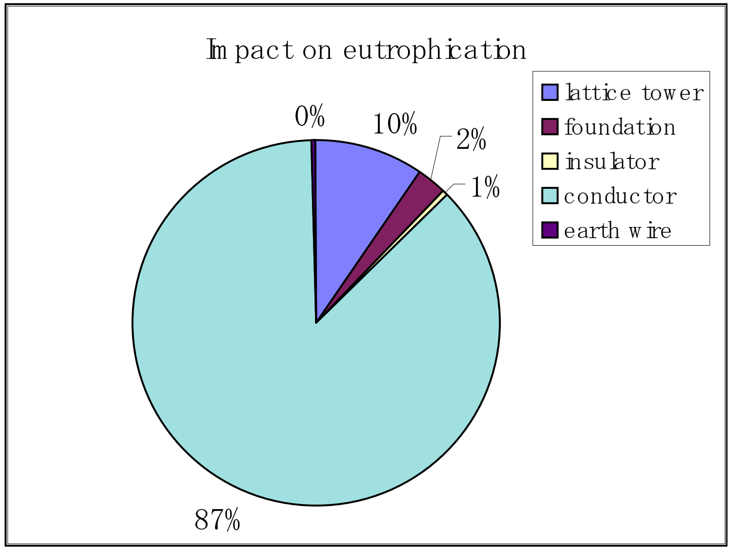


Figure 58

154kV transmission line toxicity to human－ impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
emission to air	As	1.65E-05	kg	4.70E+03	7.78E-02
	Cd	8.27E-07	kg	5.80E+02	4.80E-04
	CO	2.49E+01	kg	1.20E-02	2.99E-01
	Cr	1.65E-05	kg	6.70E+00	1.11E-04
	Hg	1.65E-05	kg	1.20E+02	1.99E-03
	Ni	7.45E-04	kg	4.70E+02	3.50E-01
	NOx	1.01E+02	kg	7.80E-01	7.86E+01
	Pb	4.96E-05	kg	1.60E+02	7.94E-03
	SO2	1.35E+02	kg	1.20E+00	1.62E+02
	V	4.14E-04	kg	1.20E+02	4.96E-02
	Zn	8.27E-05	kg	3.30E-02	2.73E-06
				total	2.41E+02

Table 43

impact category	category indicator	lattice tower	foundation	insulator	conductor	earth wire	SUM
toxicity to human	Leiden University Institute CML	28.085562	4.114438	0.94776	207.69	0.63044	241.4682

Table 44: Category indicator for each component

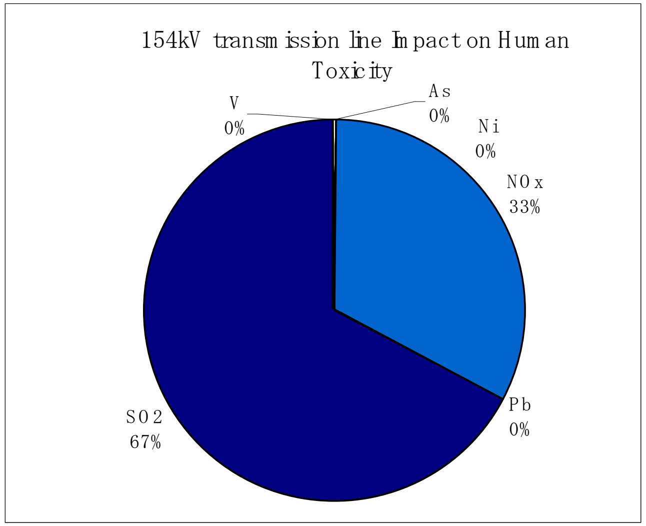


Figure 59

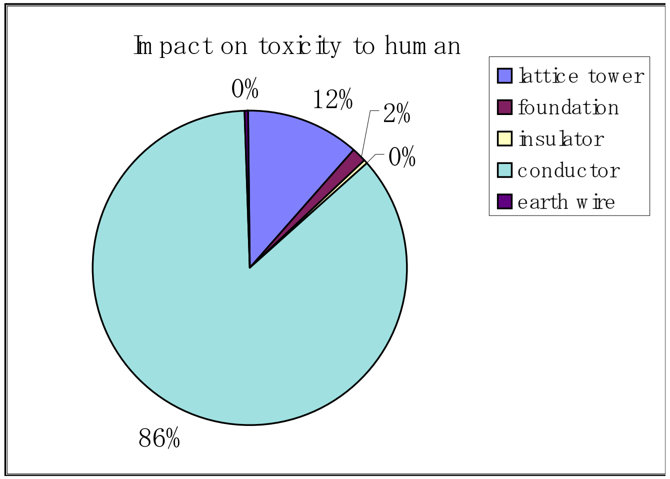


Figure 60

154kV transmission line solid wastes - impact assessment					
	item	**quantity**	**unit**	**characterization factor**	**category indicators**
solid waste	CaSO4・ 2 H2O	1.19E-01	kg	1.00E+00	1.19E-01
	red mud	5.84E+03	kg	1.00E+00	5.84E+03
	slag	2.56E+03	kg	1.00E+00	2.56E+03
	disposed PP	6.00E-02	kg	1.00E+00	6.00E-02
	unidentified solid	7.33E+02	kg	1.00E+00	7.33E+02
				total	9.13E+03

Table 45

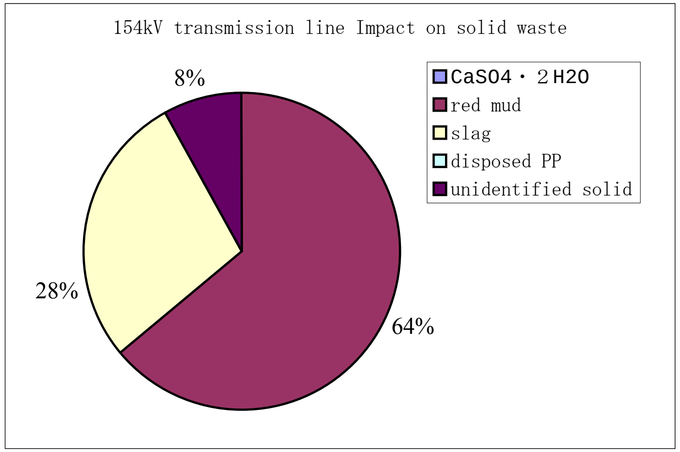


Figure 61

impact category	category indicator	lattice tower	foundation	insulator	conductor	earth wire	SUM
solid waste	Weights (kg)	2160	0	13.728	6909	50.745	9133.473

Table 46: Category indicator for each component

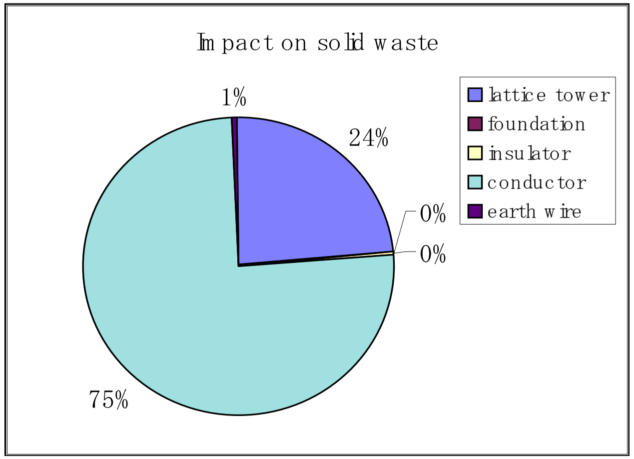


Figure 62

Solid wastes

Tables 45 and **46** and ***Figures 61*** and ***62*** indicate the results of the analysis. Red mud and Slag are the major substances in this category. While red mud is produced mainly in the manufacturing process of aluminum, slag is produced in the production of steel ingots, and zinc. As a result, conductor has the largest impact for this category followed by lattice steel tower in ***Figure 62***.

8.1.4.2 Comparison between production and use (transmission loss)

The environmental impact of the 154kV transmission line model during the manufacturing process and during use is compared under the following conditions:

Calculation condition of the transmission line model in use

To estimate transmission losses of the conductor operation, calculations were carried out using the following equation: $\text{Loss}=3 \cdot I^2 \cdot R$

Where "R" indicates the ACSR 410 mm^2 resistance of 0.0702 Ω/km and "I" is estimated using a 30% loading rate of the continuous allowable current (830 A), for ACSR 410 mm^2. The background for this setting is same as that for the LCA studies, OHL Components (ACSR). Please refer to the section 7.3.4 for details.

When assuming that the transmission line will be used for 25 years, the transmission loss over this life period can be estimated as follows:

Calculation case	Current (A)	Period (hour)	Transmission loss kWh/km	Transmission loss kWh/m
At 30% load	249	219,000	2,859,570	2,860

The span length of the transmission line is 350m and the number of circuits is two, therefore the transmission loss for the model becomes 2,002,000 kWh.

Results of inventory analysis

Table 47 and ***Figures 63*** and ***64*** show the results of the analysis. In ***Figure 63***, it is shown that materials such as aluminium, iron, and zinc, are all used for the actual manufacturing of the products while electricity production related materials such as coal, oil and uranium are mainly consumed in the use phase. In ***Figure 64*** (Emissions to air), it can be seen that CO_2, N_2O, NOx, and SO_2 are exhausted mainly from the use phase too. It also shows that the large amount of electricity consumption (fossil fuel combustion) in the use phase has greater influence on the results.

Impact assessment results

Table 48 and ***Figure 65*** show the results of the analysis. In Figure 65, it is shown that in all impact categories, the use phase has dominant impacts compared to those for the production phase. This is mainly caused by the large amount of electricity consumed as a form of transmission loss. For resource exhaustion, due to the influence of materials such as zinc, lead, aluminum, and iron, the production phase has slightly higher impacts compared to those for other categories.

154kV transmission line - Comparison between production and use Inventory Result							
	No	item	unit	total	production	use	*1 open sea
raw material [resource exhaustion]	1	Al reserves	kg	2.75E+03	2740.988		
	2	coal for coke reserves	kg	4.66E+03	4660.4387		
	3	coal for elect. reserves	kg	1.16E+05	8353.5638	1.07E+05	
	4	Fe reserves	kg	6.34E+03	6337.2848		
	5	LNG reserves kg	kg	5.61E+04	2318.9445	5.37E+04	
	6	Mn reserves	kg	40.3825	40.3824		
	7	oil reserves	kg	1.27E+05	5701.3692	1.21E+05	
	8	Pb reserves	kg	33.2792	33.2792		
	9	U reserves	kg	7.306	0.048735	7.2573	
	10	Zn reserves	kg	277.9846	277.9846		
emission to air	1	CH4	kg	19.4961	0.0803	19.4159	
	2	CO2	kg	9.08E+05	58720.941	8.34E+05	1.52E+04
	3	N2O	kg	22.8586	6.8785	9.1108	6.8694
	4	NOx	kg	622.5179	99.4739	504.7447	18.2993
	5	SO2	kg	875.7015	119.5741	635.9937	120.1337
	6	As	kg	0.004	0.000016542	0.004	
	7	Cd	kg	2.01E-04	8.271E-07	2.00E-04	
	8	CO	kg	150.4152	24.6794	123.3377	2.3982
	9	Cr	kg	0.004	0.000016542	0.004	
	10	Hg	kg	0.004	0.000016542	0.004	
	11	Ni	kg	0.1809	0.0007445	0.1801	
	12	Pb	kg	0.0121	0.000049566	0.012	
	13	V	kg	0.1005	0.00041395	0.1001	
	14	Zn	kg	0.0201	0.00008271	0.02	

:graphed see ***Figure 64 and 65***

Table 47

*1 Open sea: When intermediate products or materials are imported from abroad, gas from heavy oil combustion of marine transportation is classified into "open sea".

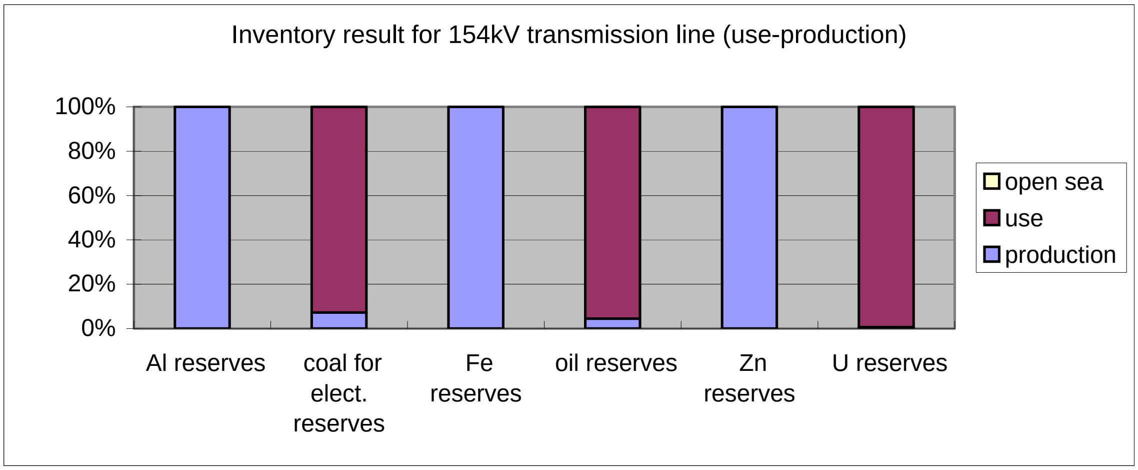


Figure 63: Resource Exhaustion

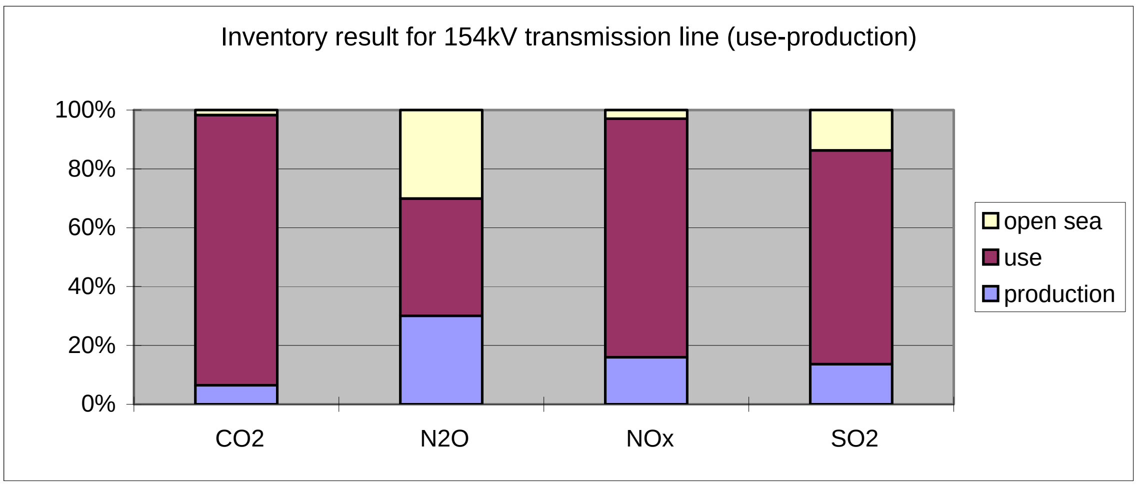


Figure 64: Emission to Air

impact category	category indicator	production	use
resource exhaustion	Inverse of total deposit in the world	1119.198	2697.203
global warming	GWP	61830.57	852369
acid rain	Acidification potential	205.6056	1105.858
eutrophication	ODP	13.09742	67.8299
toxicity to human	Leiden University Institute CML	241.4682	1415.271

Table 48: Category indicator comparison between production and use

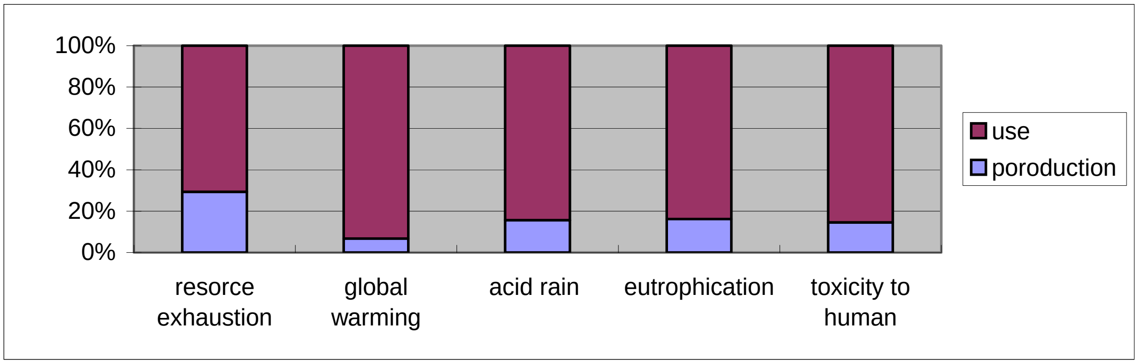


Figure 65: Category indicator comparison between production and use

8.1.4.3 Influences of recycling processes

The influences of recycling processes for the 154 kV transmission line model are investigated under the following conditions.

Calculation condition for the recycling process

Three metals (iron, aluminum, and zinc) and three components (lattice steel tower, conductor, and earth wire) are taken into consideration for the recycling process. It is presumed that 90% of each component is recycled after its removal from the facility.

Five cases compared in the study

To assess the influence of each material and component respectively on environmental impact, the five cases shown below were chosen for the comparison.

Base: No recycling process is included. Processes included for this case are production related ones only, in other words, the use phase is not included because of its dominant impact.

Case1: Base + all recycling processes (i.e. iron, aluminum, and zinc are recycled from removed lattice steel tower, conductor, and earth wire).

Case2: Base + recycling processes for conductor and earth wire (i.e. iron, aluminum, and zinc are recycled from conductor and earth wire).

Case2-1: Base + recycling processes for conductor and earth wire + zinc recycling processes for lattice tower (i.e. iron, aluminum, and zinc are recycled from conductor and earth wire along with zinc only recycled from the lattice tower).

Case3: Base + recycling processes for lattice tower (i.e. iron and zinc are recycled from the lattice steel tower).

Case	Material	Production process	Recycling process	
			Lattice steel tower	**Conductor and Earth wire**
Base		Yes	No	No
Case 1	Iron	Yes	Yes	Yes
	Zinc		Yes	Yes
	Aluminum		---	Yes
Case 2	Iron	Yes	No	Yes
	Zinc		No	Yes
	Aluminum		---	Yes
Case 2-1	Iron	Yes	No	Yes
	Zinc		Yes	Yes
	Aluminum		---	Yes
Case 3	Iron	Yes	Yes	No
	Zinc		Yes	No
	Aluminum		---	No

Table 49: Summary of the cases and their contents.

Impact assessment results

Resource exhaustion

Table 50 and ***Figure 66*** show the results of the analysis. In ***Figure 66***, comparing case 2 and case 2-1, we can see the big impact of zinc recycling process for the lattice tower. It also shows that the impact of the aluminum recycling process for conductor is not large even though almost all the conductor is recycled. In other words, zinc-recycling process is the key for this category.

Global warming

Table 51 and ***Figure 67*** show the results of the analysis. The aluminum recycling process for conductor reduces the CO_2 emissions largely. Even in case 1 the impact only decreases to less than a third of its original level, since the recycling process itself consumes additional energy emitting CO_2 and CO_2 emissions also take place in the process of LPG combustion for lattice tower member manufacturing after the iron production process.

Acid rain

The results of the analysis are shown in **Table 52** and ***Figure 68***. Emissions of NO_x and SO_2 decrease drastically in case1 and case 2 when the aluminum recycling process is included. The electricity consumption decrease for aluminum production largely benefits the impact on this category. Therefore in case 3 (without conductor recycling) the impact does not drop significantly.

Eutrophication of lakes and marshes

Table 53 and ***Figure 69*** suggest that NO_x decreases largely in case1 and case 2, showing that the aluminum recycling process, which saves electricity consumption for aluminum production, also benefits the reduction of the impact on this category.

Toxicity to human body

Table 54 and ***Figure 70*** show the results of the analysis. ***Figure 70*** indicates that NO_x and SO_2 are the main emissions relevant to toxicity to human body, having the same trend as acid rain in ***Figure 68.***

Solid wastes

Table 55 and ***Figure 71*** indicate the results of the analysis. Red mud and Slag are the major substances in this category. As red mud is produced mainly in the manufacturing process of aluminum, in case 2 (aluminum recycling case) the reduction of the impact is larger than that in case 3, in which the iron recycling process reduces slag production.

	category indicator				
	base	**case1**	**case2**	**case2-1**	**case3**
Al reserves	8.07E+01	4.57E+00	4.57E+00	4.57E+00	8.07E+01
coal for coke reserves	9.00E+00	2.31E+00	8.00E+00	8.11E+00	3.30E+00
coal for elect. reserves	1.61E+01	2.74E+00	3.63E+00	3.47E+00	1.52E+01
Fe reserves	8.35E+01	1.63E+01	7.36E+01	7.36E+01	2.62E+01
LNG reserves kg	2.25E-02	4.48E-03	4.23E-03	4.12E-03	2.28E-02
Mn reserves	8.08E+00	8.08E+00	8.08E+00	8.08E+00	8.08E+00
oil reserves	4.14E+01	2.00E+01	1.79E+01	1.77E+01	4.35E+01
Pb reserves	2.38E+02	7.12E+01	2.13E+02	7.12E+01	9.63E+01
U reserves	1.08E+01	7.98E+00	7.25E+00	6.92E+00	1.15E+01
Zn reserves	6.32E+02	1.84E+02	5.64E+02	1.84E+02	2.52E+02
	1.12E+03	3.17E+02	9.00E+02	3.78E+02	5.37E+02

Table 50: 154kV transmission line model - change of impact on resource exhaustion among recycle cases

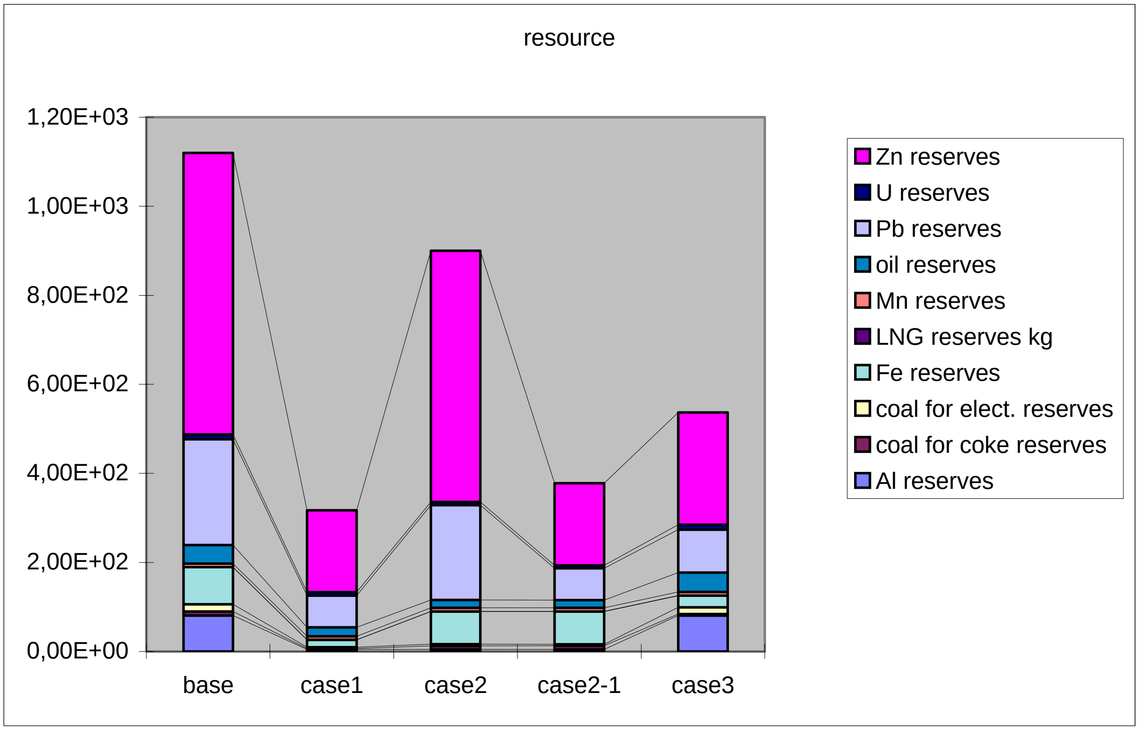


Figure 66

	category indicator				
	base	**case1**	**case2**	**case2-1**	**case3**
CH_4	8.83E-01	1.03E+00	9.28E-01	8.87E-01	9.83E-01
CO_2	6.00E+04	1.75E+04	2.66E+04	2.65E+04	5.08E+04
N_2O	1.87E+03	6.39E+02	6.94E+02	6.85E+02	1.81E+03
	6.18E+04	1.81E+04	2.73E+04	2.71E+04	5.26E+04

Table 51: 154kV transmission line model - change of impact on global warming among recycle cases

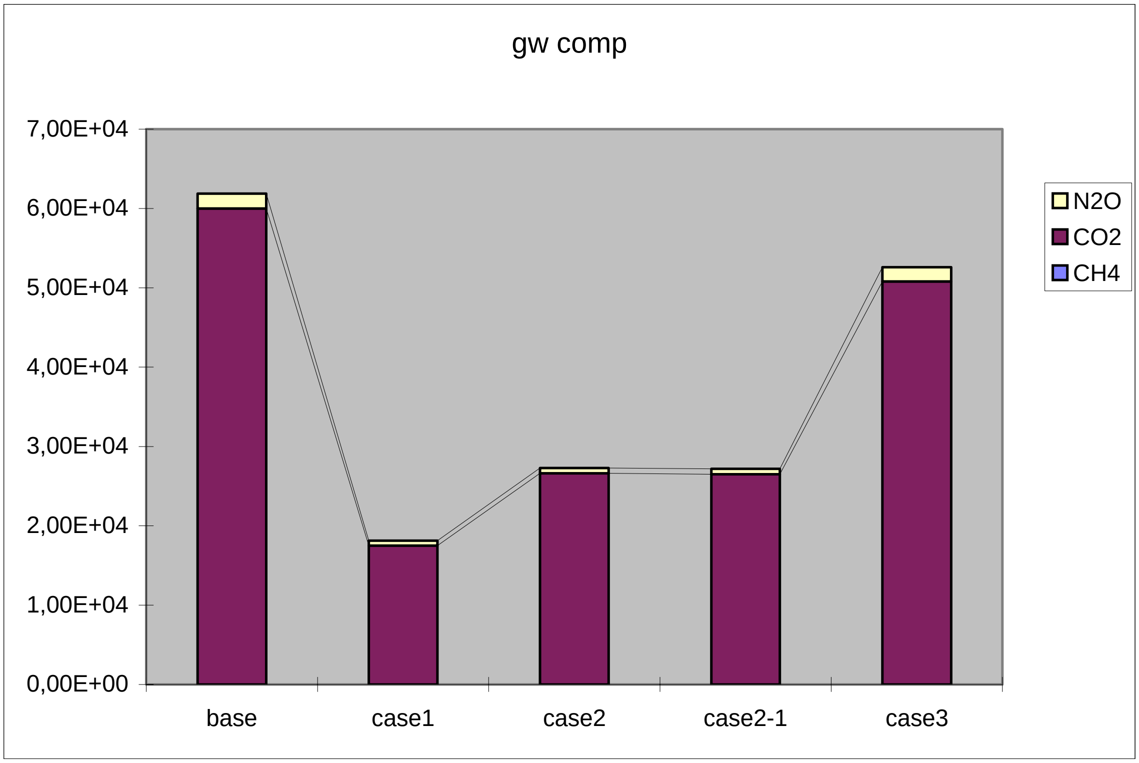


Figure 67

	category indicator				
	base	**case1**	**case2**	**case2-1**	**case3**
NOx	7.05E+01	1.22E+01	1.53E+01	1.49E+01	6.74E+01
SO_2	1.35E+02	1.94E+01	2.74E+01	2.59E+01	1.27E+02
	2.06E+02	3.16E+01	4.27E+01	4.08E+01	1.95E+02

Table 52: 154kV transmission line model - change of impact on acid rain among recycle cases

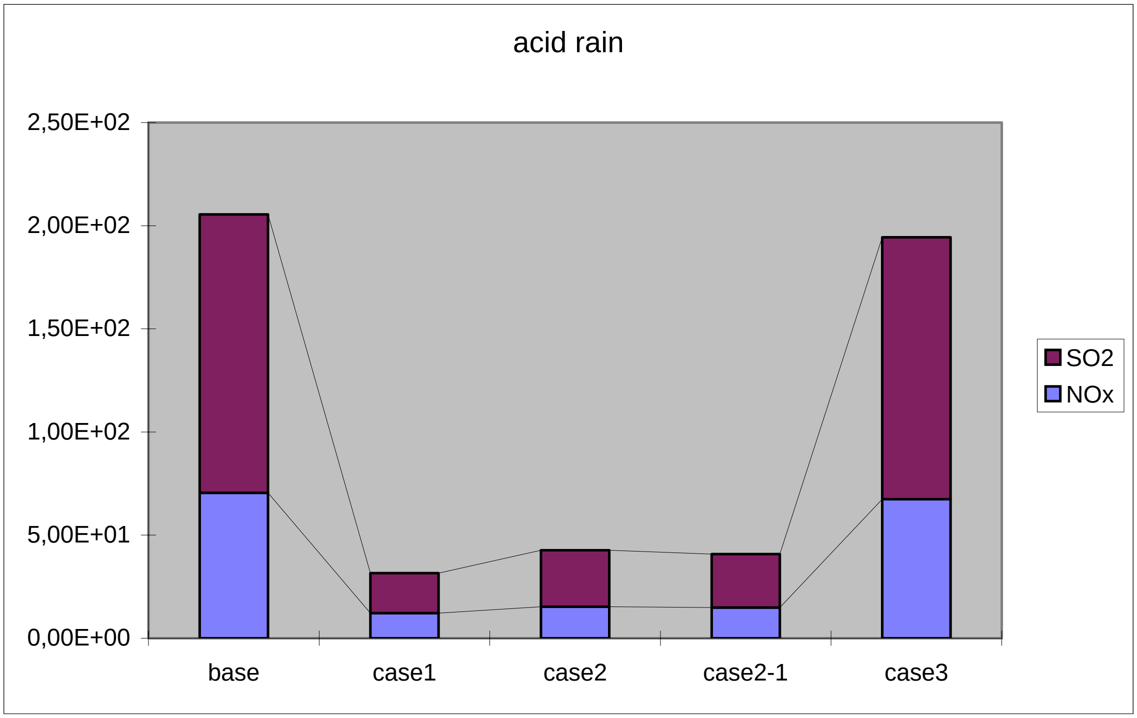


Figure 68

	category indicator				
	base	**case1**	**case2**	**case2-1**	**case3**
NOx	1.31E+01	2.26E+00	2.85E+00	2.77E+00	1.25E+01
	1.31E+01	2.26E+00	2.85E+00	2.77E+00	1.25E+01

Table 53: 154kV transmission line model - change of impact on eutrophication among recycle cases

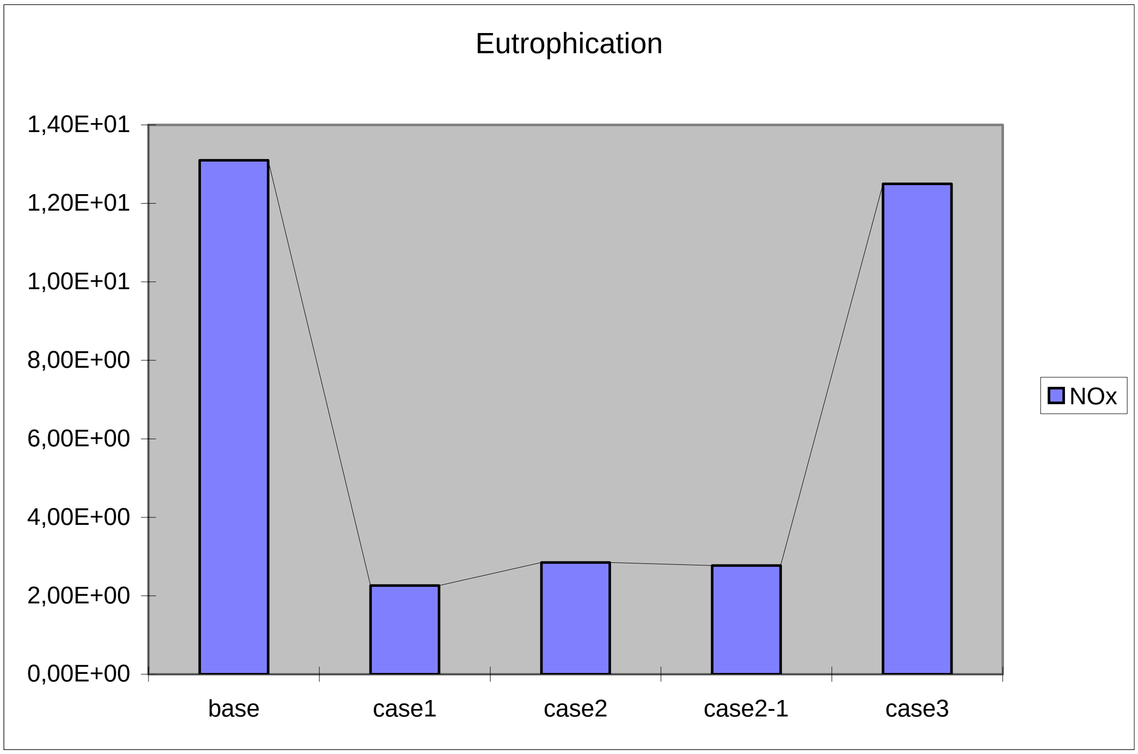


Figure 69

	category indicator				
	base	**case1**	**case2**	**case2-1**	**case3**
As	7.78E-02	9.06E-02	8.17E-02	7.81E-02	8.66E-02
Cd	4.80E-04	5.59E-04	5.04E-04	4.82E-04	5.34E-04
CO	2.99E-01	4.36E-02	6.30E-02	6.08E-02	2.79E-01
Cr	1.11E-04	1.29E-04	1.16E-04	1.11E-04	1.23E-04
Hg	1.99E-03	2.31E-03	2.09E-03	1.99E-03	2.21E-03
Ni	3.50E-01	4.08E-01	3.68E-01	3.52E-01	3.90E-01
Pb	7.94E-03	9.25E-03	8.35E-03	7.98E-03	8.84E-03
V	4.96E-02	5.78E-02	5.22E-02	4.99E-02	5.53E-02
Zn	2.73E-06	3.18E-06	2.87E-06	2.74E-06	3.04E-06
NOx	7.86E+01	1.36E+01	1.71E+01	1.66E+01	7.51E+01
SO_2	1.62E+02	2.33E+01	3.28E+01	3.11E+01	1.53E+02
	2.41E+02	3.75E+01	5.05E+01	4.83E+01	2.28E+02

Table 54: 154kV transmission line model - change of impact on toxicity to humans among recycle cases

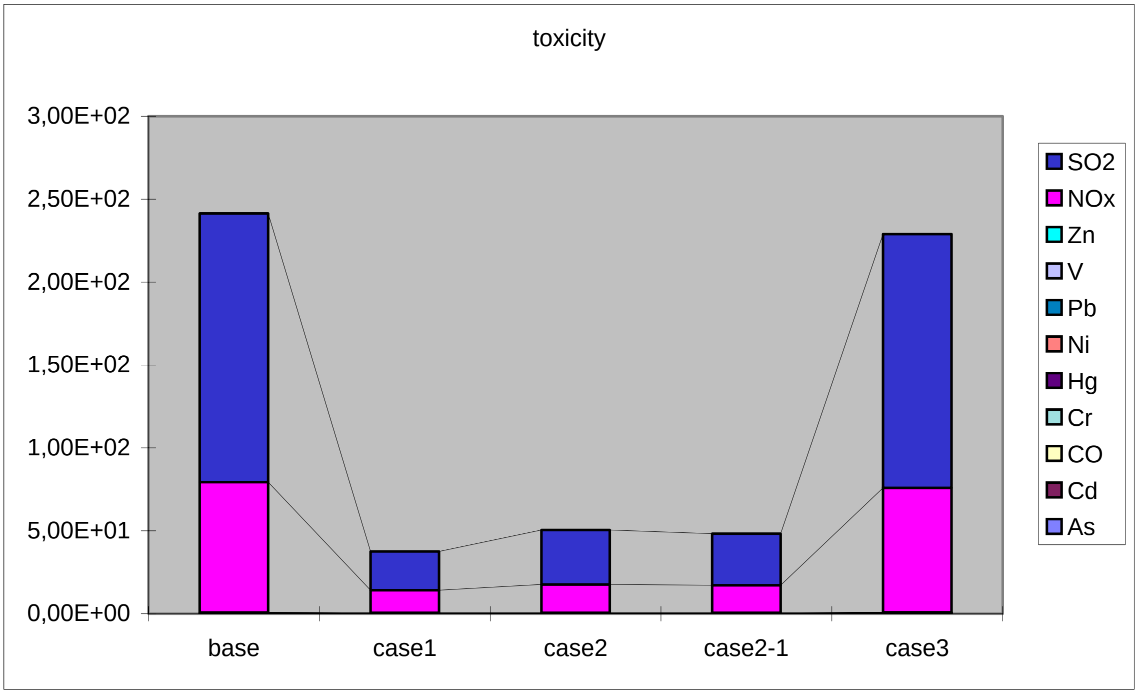


Figure 70

	category indicator				
	base	**case1**	**case2**	**case2-1**	**case3**
$CaSO_4 \cdot H_2O$	1.19E-01	1.19E-01	1.19E-01	1.19E-01	1.19E-01
red mud	5.84E+03	2.88E+02	2.88E+02	2.88E+02	5.84E+03
slag	2.56E+03	5.62E+02	2.26E+03	1.88E+03	8.58E+02
disposed PP	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02
unidentified solid	7.33E+02	3.62E+01	3.62E+01	3.62E+01	7.33E+02
	9.13E+03	8.87E+02	2.58E+03	2.20E+03	7.44E+03

Table 55: 154kV transmission line model - change of impact on solid waste among recycle cases

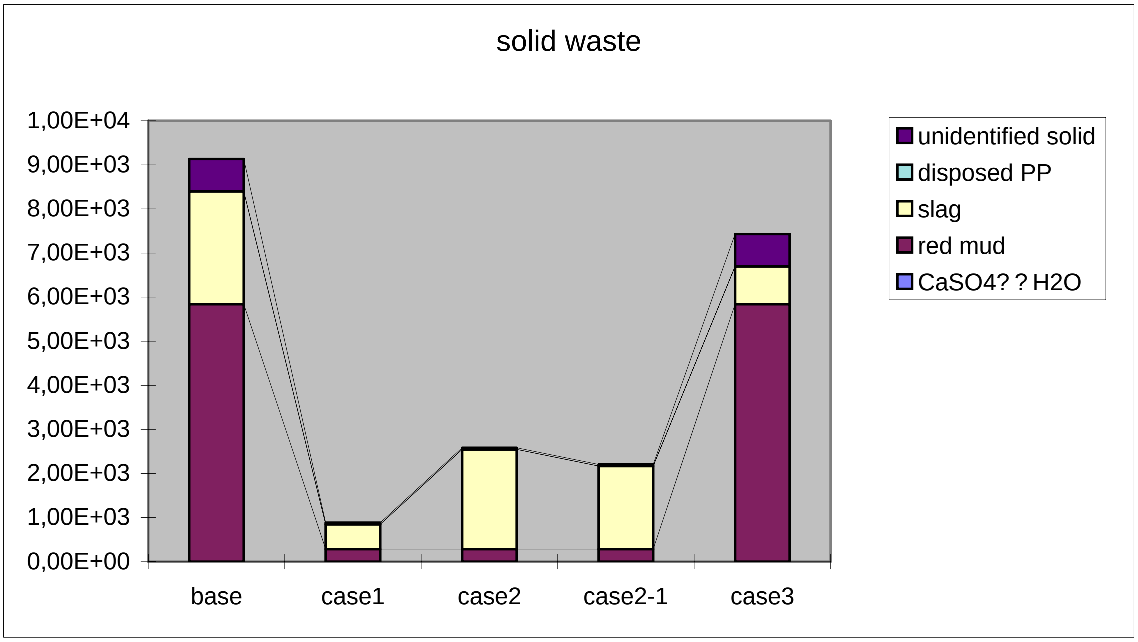


Figure 71

8.1.5 Conclusions and recommendations

8.1.5.1 Conclusions

Environmental Impacts caused from each component

- For gas emission related categories such as global warming, acid rain, etc., the conductor has more impact than other components due to its large amount of electricity consumption.
- With regard to resource exhaustion, the lattice tower has the largest impact because of its consumption of zinc and lead

Environmental Impacts Comparison between production and use (transmission losses)

- In all categories the use phase has dominant impact compared to the production phase. The ratio of production to use is about 1 to 9.

Influences of recycling processes

- Environmental impact does not decrease in proportion to the recycled material volume of removed components because additional energy is required for the recycling processes themselves.
- Aluminum recycling plays an important role in reducing environmental impacts in gas emission related categories.

8.1.5.2 Recommendations

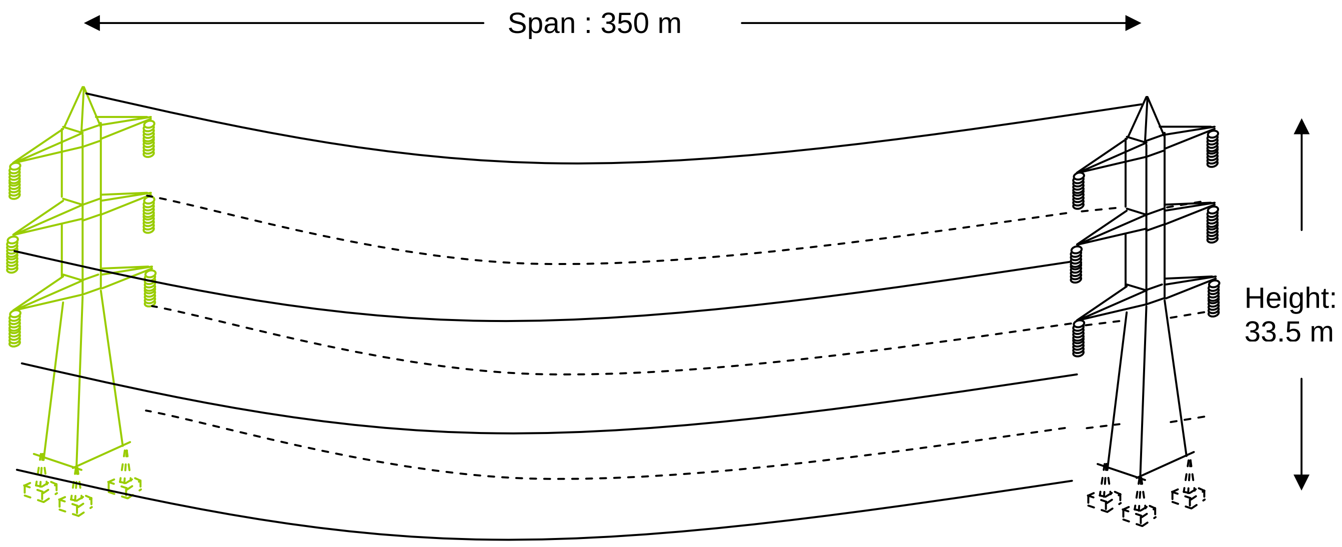
To reduce environmental impacts caused by OHLs (excluding power transmission losses), recycling aluminum of the conductor seems the most effective way and efforts should continue in promoting aluminum recycling. Furthermore in terms of natural resource preservation, recycling lattice towers especially zinc recycling, is effective. However zinc-recycling systems have not been established sufficiently compared to steel recycling systems, this might be another area to be focused on.

Concerning transmission losses, the development of low resistance conductors seems an effective option. Upgrading of OHLs to higher voltage ones might be other option, however, further more detailed LCA studies, which covers the broader power system are needed to conclude this.

It should be noticed that this study was conducted based on the data mainly obtained in Japan where environmental impacts stemming from power transmission losses are largely influenced by its power generation sources. Knowing from the results of the study that power transmission losses have major environmental impacts, it is recommended that the situation (such as power generation sources) in each country should be reviewed when interpreting the results in each country.

ATTACHMENT 1 (see 8.1.3.1)

LCA Model for a 154kV 2cct OHL (one span + one structure)



Components drawn in black in the above picture are included as a model.

Component	Specification	Unit	Quantity	Note
Structure	Lattice steel tower	ton	7.5	
	Foundation	m^3	10.3	
Conductor	ACSR	m	2,100	350*6
	Galvanized stranded steel wire	m	350	(Earth wire)
Insulator	Porcelain disc	piece	66	11*6

8.2 Impacts from 1 km of 400 kV Overhead Line (Denmark)

8.2.1 Introduction

A major Danish LCA study has been conducted in the Danish electricity supply industry. This chapter gives a brief introduction to the study and outlines the results relating to the standard component "400 kV overhead line". It also includes a sensitivity analysis on the effect of assumed life time on the study results.

It continues with a comparison between the LCA analysis for the standard component overhead line and a recent LCA analysis for a completely new design 400 kV overhead line, in which the visual aspect of the tower (structure) was the focus.

8.2.1.1 Background of the Danish study

Purpose

The project concerning the life cycle assessment of Danish electricity and CHP (heat generated or co-generated by an electricity production unit) was carried out in the period 1998-2000. It is one of the most comprehensive of its kind in Denmark with respect to both resources and scope as it included all relevant electricity and CHP generation technologies as well as the transmission and distribution of electricity and CHP. The main purpose of the project was to describe the impact on the environment and the consumption of resources for Danish electricity and CHP with the selected functional units of 1 kWh of electricity and 1 kWh of CHP. It was also intended to provide a true base for other companies using LCA methods as electricity is an important resource in many products.

Standards

The life cycle assessment of Danish electricity and CHP was carried out in accordance with the international standards in the ISO 14040 series (ISO 14040, 1997). The ISO standards set the general principles for the carrying out of life cycle assessments. For the purpose of further specification of the guidelines in the ISO standards, the assessment has been based on a Danish development within LCA using the Danish Environmental Protection Agency's EDIP (Environmental Design of Industrial Products) method and corresponding software tool.

Quality Assurance

To ensure the quality of the project and the future reliability of the results, a third-party critical review was carried out. The quality assurance was carried out by a team from the Institute for Product Development at DTU, the Technical University of Denmark, and the Energy Systems Group at Risø National Laboratory. The third-party quality assurance was financed by the Danish EPA's programme for cleaner products, etc. as a method development project on third-party quality assurance. The conclusions from the third-party review have been included in the main report.

Effort

10 man-years were spent on the total study. Around 15 man-months were dedicated to the study concerning the transmission grid system.

8.2.2 The Danish Transmission Grid

The most important environmental impacts from the transmission of electricity originate from volume waste and the greenhouse effect. Volume waste stems partly from soil waste in connection with construction projects and the leaving of concrete foundations in connection with the demolition of plants. However, most of the volume waste originates from coal mining in open mines, which involves the removal of large volumes of soil – defined as waste.

The greenhouse effect is primarily caused by the production of electricity for grid losses, resulting in the emission of greenhouse gases. Emissions from the production of electricity to cover grid losses are ten times larger than emissions from the building and demolition of the transmission grid.

8.2.3 400 kV Overhead Line

The model used a line with the Danube tower, with a 400 kV circuit and a 150 kV circuit installed. See **Figure 72**. The fact that a considerable number of different types of towers have been used in the 400 kV transmission grid has been disregarded. Furthermore, not all 400 kV lines have been constructed as combined lines.

In terms of the type of conductor, it has been assumed that the 400 kV circuit has been installed with twin Martin conductors (772 square mm of steel and aluminium). The 150 kV circuit has single Martin conductors. The overhead line has two Dorking earth conductors (153 square mm of steel and aluminium). All conductors have a greased steel core for corrosion protection.

Figure 72: Erection of Danube tower with a 400 kV circuit and a 150 kV circuit.

The Martin conductor is the standard type of conductor used in Eltra's 400 kV grid. The use of conductors has been fixed at 105 per cent of the line length due to sags, etc.

The insulator strings for the 400 kV circuits have been constructed as individual suspension strings with 21 glass insulators. The insulator strings for the 150 kV circuits have been constructed as individual suspension strings with 12 glass insulators.

The average span between two towers has been fixed at 333 metres, meaning that three towers have been erected per kilometre of overhead line. This is a relatively high number of towers, as many old 400 kV lines have spans of up to approx. 450 m.

It is assumed that all towers are suspension towers. Consequently, anchor towers and running angle suspension towers have not been included. The subsequent error is assumed to be relatively modest when compared with the general simplification of the use of the Danube tower as the basis of the study.

As can be seen, a number of relatively severe assumptions have been used for the assessment, i.e. the use of the largest types of towers and conductors and a relatively small span. The lifetime of a 400 kV overhead line has been fixed at 40 years. Any extensions of the lifetime of the plant have not been included.

The statement of material volumes is generally based on supplier information. Statements of transport distances, etc., are based on estimates. The exchange of material in the operation process is based on operating experience as well as earlier studies (with regard to zinc leaching).

The above statement does not include the volume of zinc in iron components of the insulator strings, nor the galvanisation of the steel wires in the conductors. These volumes are, however, insignificant in comparison with the volumes of zinc used for the galvanisation of the towers.

The statement of resources does not include the following components, where the materials consumption in overhead lines has been deemed to be insignificant.

- Steel bolts with nuts and washers
- Pins in insulator strings (steel)
- Vibration dampers (steel, aluminium)
- Spacers (steel, aluminium, neoprene rubber)
- Phase weights (if any)
- Copper earthing (if any) around tower
- Flight warning spheres (if any) (aluminium/fibre glass)
- Flight warning lamps (if any) and their electricity consumption
- Signs (iron/plastic).

8.2.4 Environmental Impacts

All in all, the environmental impact of 1 kWh of electricity delivered to a Danish consumer will only to a very insignificant extent be related to the physical transmission grid, see ***Figure 73***. Thus, approx. 90 per cent of the environmental impact originates from the production of electricity. Furthermore, the distribution of electricity causes an additional 8 per cent of the environmental impacts. With respect to the transmission and distribution of electricity, it is notably the grid losses that generate environmental impacts. In Denmark electricity production is largely based on fossil fuels.

If you exclude grid losses, only 0.3 per cent of the environmental impact can be related to the physical parts of the overhead transmission lines. However, this share will increase as production changes from fossil fuels to renewable energy.

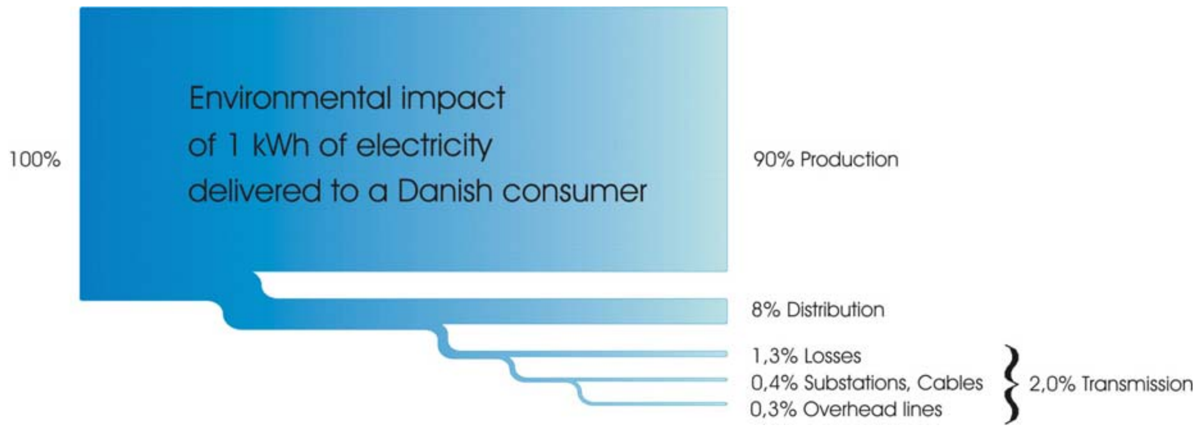


Figure 73: Environmental impact in the Danish electricity system broken down into the various elements.

The transmission grid has three life cycle phases: erection, operation, demolition. If the impacts are distributed over the three phases, approx. two thirds relate to grid losses and only one third to the actual plant.

Eltra has carried out a number of detailed studies of the physical transmission grid for the purpose of categorising the impacts.

The volume impact (g or cubic metre) from 1 km of 400 kV overhead line is stated in **Table 56**. It includes the impact during all three phases of the life cycle of the overhead line, but exclusive of grid losses.

Categories	**Volume**	**Unit**
Greenhouse effect	3.6	tons of CO_2 equivalent
Acidification	19.5	kg of SO_2 equivalent
Ozone formation	0.0036	g of CFC_{11} equivalent
Nutritive salts impact	17.2	kg of NO_3 equivalent
Toxic water pollutants	107419	m^3 of water
Toxic air pollutants	446.800.000	m^3 of air
Toxic soil pollutants	231	m^3 of soil
Voluminous wastes	8.8	Tonnes
Hazardous wastes	4.8	kg
Radioactive wastes	18.0	g
Slag and ash	43.5	kg

Table 56: Pollution related to 1 km of 400 kV overhead line during lifetime exclusive of grid losses.

The LCA method used divides the environmental impacts into eleven categories and includes global, regional and local impacts.

Activities in connection with the production, transport, erection, operation, inspection and demolition and the processing of recycled material are summarised in **Table 56**. The table shows the volume of pollutants emitted during the total life cycle of 1 km of 400 kV overhead line. Thus the greenhouse effect is approx 3.6 tonnes of CO_2 emission.

The information of 3.6 tonnes of CO_2 emissions is not in itself useful for many purposes. However, when compared with the environmental impacts from overhead lines made with other types of material, etc., or a solution with cables or an increase in capacity of transformers, the LCA information is indeed valuable.

From ***Figure 74*** it can be seen that foundations are the principal source of most environmental impacts. The production of cement, which is very energy-intensive, and steel for the reinforcement of the foundations stand out especially. An important factor is the assumption that the foundations cannot be recycled. Consequently, only the top of the foundations are removed during demolition, whereas the rest remains underground on site. Therefore, those materials cannot form part of a recycling process and the foundations have full impact.

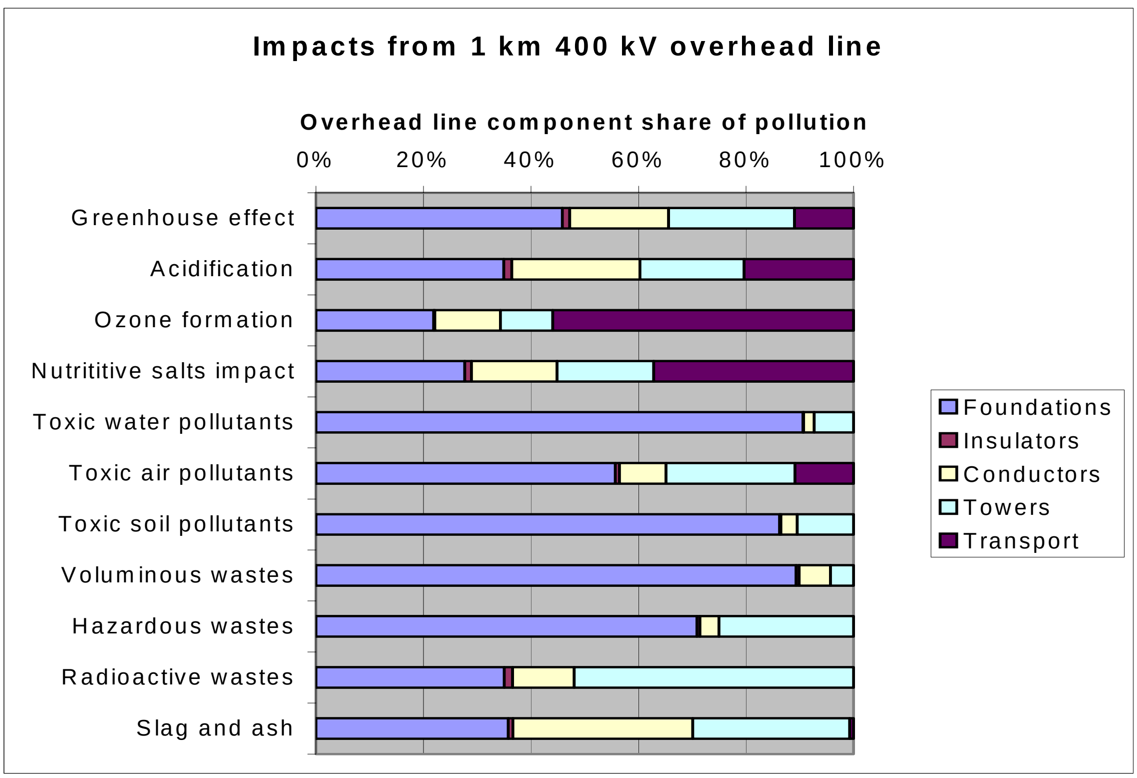


Figure 74: Categorisation of environmental impacts into main components. Grid losses are not included in this categorisation either.

Insulators are only small components in an overhead line, and this can also be seen in **Figure 74**. It is assumed in the case of insulators that only metal components are recycled and that the toughened glass will be deposited in a landfill.

On the other hand, the conductors are major components in the overhead line and it is assumed that 90 per cent of the materials will be collected and recycled. In this way, the overhead line impacts are credited with the energy-intensive processes in connection with the production of aluminium and steel.

The towers are the largest metal components. Like the conductors, the towers are expected to be dismantled and reused in new products. Here too, the recycling process is credited to the towers.

Transport includes all transport from the factory to the place of erection, haulage vehicles, cars and helicopters for inspection and haulage vehicles for dismantling. Finally, transport for recycling has also been included.

Around 75 per cent of the environmental impact is related to the foundations and the towers.

8.2.5 Comparison between two different tower (structure) types in terms of environmental impact

A special study has been made to investigate the difference between two different towers in terms of environmental impact. The purpose was to test the LCA technology on a practical task.

Figure 75: Picture of Danube tower (left) and new design tower (right).

The Danube tower is designed for two 400 kV circuits or one 400 kV circuit plus one or two 150 kV circuits. The typical construction in Denmark is one 400 kV circuit and one 150 kV circuit, as shown in ***Figure 75***.

The new structure (tower) is designed for one 400 kV circuit. So an additional 150 kV PEX cable circuit must be laid if it is to be technically equivalent to a Danube tower.

Figure 76 shows a comparison of the two solutions.

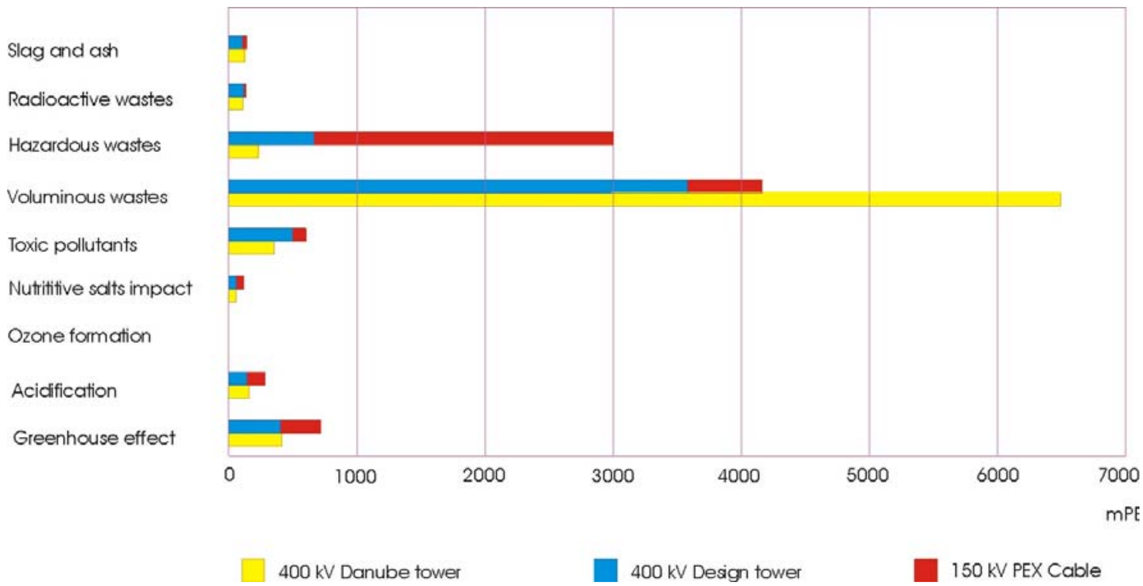


Figure 76: Comparison of double circuit Danube tower and new single circuit design structure(tower), including one 150 kV PEX cable circuit (mPE = milli person equivalent).

The foundation of a Danube tower uses 36 per cent more concrete than the new design tower. Only a small part (about 10%) of the concrete can be recycled and the Danube tower therefore features the largest environmental impact in this category.

If volume waste is disregarded, the new design tower will have a larger environmental impact than the Danube tower in the other categories. The main reasons are that stainless steel has been used in the construction of the head of the design tower and that a 150 kV PEX cable is needed to make the solution as good as the Danube tower solution.

8.2.6 Environmental impact sensitivity to the lifetime of the overhead line

The lifetime of an overhead line has been fixed at 40 years in the Danish study. The main reason is that the Danish climate makes it necessary to protect galvanised towers and exchange conductors, insulators, etc. every 30-50 years.

Table 57 shows a comparison between a double-circuit Danube tower with a lifetime of 40 years and 80 years. The impact is reduced by 40-50% when the lifetime is doubled.

	Environmental impacts (%)	
	Lifetime 40 years	**Lifetime 80 years**
Greenhouse effect	100 %	56 %
Ozone formation	100 %	50 %
Acidification	100 %	53 %
FotoChemic ozon-1 (lavNOx)	100 %	54 %
Nutritive salts impact	100 %	54 %
Toxic human pollutants	100 %	61 %
Toxic eco pollutants	100 %	60 %
Toxic persistent pollutants	100 %	61 %
Voluminous wastes	100 %	50 %
Hazardous wastes	100 %	58 %
Radioactive wastes	100 %	56 %
Slag and ash	100 %	52 %

Table 57: Comparison of environmental impacts (milli person equivalent, relative) of a double-circuit Danube tower.

A detailed study of the lifetime of the different components of an overhead line should be considered if you want to improve the result of your LCA study. Local conditions usually influence how the lifetime is to be estimated.

8.2.7 Conclusions

In Denmark, electricity production is largely based on fossil fuels. Therefore only 0.3 per cent of the environmental impact of the Danish power system is related to the physical parts of the transmission overhead lines. This will change if electricity production changes from fossil fuel to other technologies in future.

The environmental impact from overhead lines is in particular associated with the type of foundation and the choice of materials in the tower construction. In Denmark, 3/4 of the environmental impact from overhead lines is thus linked to these two components.

A comparison between the two types of structures (towers) will favour the type of tower that carries most circuits.

The estimated lifetime of the overhead line has a significant influence on the impacts. If you double the lifetime, the impact tends to be reduced by 40-50%.

8.2.8 Recommendations

Using LCA studies to reduce the environmental impact requires an overview of the entity that the LCA study forms part of. This is particularly the case if a utility is willing to invest money in order to reduce the environmental impact. Otherwise, it is very likely that investment would not be made efficiently.

Technically, a reliable way to reduce the environmental impact from overhead lines is to ensure that a transmission tower is designed for two or more circuits. In this way the environmental impact related to foundation and towers tends to be minimised per 1 kWh of electricity transported. New ways to make foundations could be another effective way to minimize the environmental impact.

LCA studies of components in the power system are still evolving. As far as models for the transmission grid are concerned, you can use the figures as a supplement in evaluation of, for example, different types of towers or foundation technologies.

The lifetime of the different components of the overhead line should be estimated individually.

9. CONCLUSIONS AND RECOMMENDATIONS

The terms of reference for working group B2-15 called for the analysis of Life Cycle Assessment (LCA) methods and existing tools to ascertain their range of application for overhead lines. They also called for the development of methodologies as appropriate for Life Cycle Assessment of Overhead Lines, and the establishment of recommendations to provide as complete a picture as possible of the interactions of an overhead line with the environment and to provide decision makers with information which identifies opportunities for environmental improvement.

The working group has presented the background to LCA and undertaken a broad review of the ISO 14040 series standards for performing LCA studies indicating some appropriate models for overhead lines and overhead line components. Comprehensive power system and overhead line LCA studies carried out in Scandinavia have been appraised and summarised.

A very comprehensive evaluation and comparison of LCA software packages from a number of different countries (Japan, France and the Netherlands) has been carried out. This describes, for the different phases of the LCA study, how the various packages provide data, the data sources availed of, and how the data is used in the different phases. It provides an important exposition of LCA general software operation and outlines some differences between the packages.

A qualitative overview of life cycle impacts and issues, including recycling, has been provided for the principal overhead line components. Structures, foundations and earthing systems, conductor and insulators have been dealt with and in addition construction and maintenance. The working group has been fortunate to have had the capacity to provide some detailed LCA studies on overhead line components (lattice steel tower, ACSR conductor, and porcelain insulators) and of two overhead line types as systems. These studies expose the methodologies used fully and the interaction of the components and overhead lines with the environment and are a most valuable insight into the modalities of performing LCA studies.

Based on the work described above across the range of LCA issues investigated and informed by the studies undertaken within the working group and elsewhere conclusions are presented and recommendations made. It should be noted however that LCA is only one of many tools to assess and reduce the impact or interaction of overhead lines and the environment. As such it is a very useful tool amongst a number that overhead lines engineers and planners use and results should be evaluated in this broad context.

Another important point to note is that the nature of transmission systems and overhead line design, construction, maintenance and operation can differ significantly from one country to the next as well the type and mix of generation of electricity.

9.1 Conclusions

9.1.1 LCA Development and ISO 14040 Series

- LCA studies and methodologies developed from the sixties and early seventies driven by the realisation of the finite character of the non-renewable resources of the Earth and effects such as global warming, accelerated by pollution resulting from industrial processes. In the eighties European and U.S. consultants and research institutes further expanded and refined the methodologies with the Society of Environmental Toxicology and Chemistry (SETAC) emerging as the focal point for technical developments in LCA.

- LCA became recognised as a potentially powerful environmental management tool and is increasingly being used in environmental management systems of companies as well as by governments in the policy making process. The LCA approach and methodology is also not static and is continually being developed.
- All LCAs performed up to the mid nineties were in industry and most concentrated on the inventory analysis stage. From the mid nineties onwards some large scale studies on electric power systems, including overhead line networks, were undertaken in Scandinavia. The analysis of LCA application to overhead lines undertaken for this technical brochure is the first of its kind.
- The **ISO 14040** ***Environmental Management- Life Cycle Assessment*** series, produced in the late nineties, deal with the principles and framework for conducting and reporting LCA studies. Life Cycle Assessment must include definition of goal and scope of the study, inventory compilation of relevant inputs and outputs to a products system (inventory analysis), evaluation of the potential environmental impacts associated with those inputs and outputs (impact assessment), and interpretation of the results of the inventory analysis and impact assessment phases in relation to the goal of the study.
- The ISO 14040 series methodology is suitable for application to overhead lines and overhead line components. A number of models suitable for studies on overhead lines and overhead line components have been proposed in the context of the product system and its boundaries. Function and functional unit and data quality requirements have been dealt with.

9.1.2 Scandinavian LCA studies

- Two large LCA studies on power and transmission systems have been completed in Scandinavia – one in Sweden and one in Denmark. The methods were largely the same, and the results are expressed in the same functional unit, i.e. environmental impact per 1 kWh of electricity delivered to the consumer. The Swedish study is a life-cycle inventory, not a complete LCA, and for reporting purposes it is divided into eight different typical customers. Major differences in resource consumption and environmental impacts are reported for transmission and distribution lines. Transmission losses to a national grid customer amount to 2 per cent while for household customers they are 9 per cent.
- The Danish study shows that the most significant environmental impact of the total electrical system is due to generation while the contribution from transmission is relatively small (see also 9.1.7 below). However network losses are a major source of environmental impact from power lines. The Danish project is reported in the form of environmental-impact profiles in which a number of environmental effects, from the greenhouse effect to slag and ash, are expressed in person equivalents. The environmental impact resulting from the transmission system is less than 1 per cent of Danish average personal environmental impact.

- The results of the Swedish and Danish studies show several similarities between countries regarding, for example, resource consumption for the lines themselves and transmission losses. There are also substantial differences. The latter are connected with the particular generation system in the country concerned and, accordingly, the environmental effect associated with generation of the electricity that is required to cover losses. Principally, electricity generation is based on hydro and nuclear power in Sweden and coal-fired power plants in Denmark. This results in very different choices with respect to technology, action area, research etc.

9.1.3 Comparison of LCA software

- LCA is a very labour intensive exercise and LCA software packages have been developed. LCA software packages provide databases of unit processes and assist in connecting process data relatively. Normalisation of all the input/output for every unit process to the functional unit of the final product is carried out. LCA software also supports calculation of environmental impact from the life cycle inventory results using the database on category indicators and has support functions for sensitivity analyses.
- The LCA software packages examined and compared have functions in common and they reduce time and labour for those performing LCA studies. However there are several functions which are different between LCA software packages and process data stored in each LCA software package is also different. Therefore it seems that consistent results cannot be obtained between different LCA software packages, and there is little meaning in comparing the final values of results derived from several different LCA software packages. Basic database, method of inventory calculation, impact assessment method, and weighting method may vary according to the software package. Although it would be beneficial to develop criteria to select software or choose the type appropriate for the intended study this task must be left for the future.

9.1.4 LCA Overview of OHL components

9.1.4.1 Structures, Foundations and Earthing Systems

Recycling of metallic structures is common practice, with a very high percentage recycled. Material from metallic structures dismantled is considered as raw material with good value. Even if some considerations are necessary when recycling painted members of towers, all metallic parts can be recycled.

Dismantled wooden poles can be used for several purposes such as paddocks, scaffolds, retaining walls for roads, emergency structures, road barriers, etc. In some countries the demand for such recycled poles is such that it cannot be met by the utilities. Recycling of treated wooden poles is not common practice. If recycled, the overall rate of recycling (reuse and recycling) may be in the range between 50% and 100%.

Recycling of the materials in concrete poles can reach a very high percentage. In modern plants 100% of concrete and reinforcing steel can be recycled.

Foundations are normally only removed to a certain level below the surface, typical values are between 50cm and 100cm. The recycling of foundations follows the same principles as for structures. If foundations are recycled then this is more often done on site than in plants and depends on the possibility for access to the site and on the amount of mass to be recycled.

Earthing systems are made of steel or copper. Whether they are removed completely or not varies from country to country. Depending on the kind of agriculture and the kind of cultivation as well as on the demands from landowners and authorities, the systems may remain in the ground below a certain depth. Typical such values are below 50 and 100cm.

9.1.4.2 Conductors

Suitable processing and disposal treatments are carried out on the hydrochloric acid and water produced in manufacturing conductor galvanised steel wires in manufacturing facilities, and this results in a minimal influence on the environment. Corroded ACSR conductors do not in themselves cause an environmental pollution problem. Nor do anti-corrosion conductors because the grease used to fill the interstices of the conductor is resistant to heat and cold and is chemically neutral; the influence on the natural environment is generally negligible in normal use.

Both the aluminium wire scraps and steel core wire scraps which are produced in the dismantling and manufacturing processes for conductors usually have a very high rate of recycling. A suitable method has not been established for recycling the anti-corrosion grease used to protect conductors, and this is a subject for future study.

9.1.4.3 Insulators

Material from metallic pieces is considered as raw material with good value. 100% of it can be used. Glass recycling can be used for low quality glass such as bottles, but most of the time it is used, as is recycled porcelain, for backfill. The polymer housing of the composite insulator is very difficult and expensive to recycle. This cost is higher than the one produced from the petro-chemical industry.

9.1.5 LCA Overview of Construction and Maintenance

9.1.5.1 Construction

The construction phase can have significant impacts on the environment and these can be the major ones during the lifetime of an overhead line in some categories (apart from losses during operation). Access roads and the right of way need to be cleared, material is transported onto site, and building construction plant is working. All these measures come to an end after commissioning of the line. The land can then be restored as required by the authorithies or by landowners. It is in the interest of utilities to keep the erection time to a minimum.

9.1.5.2 Maintenance

Maintenance requires all the operations necessary to keep the line in such condition that it fulfils its given tasks. Periodic inspections of the line's components are therefore necessary. This includes conductors and earth wires, fittings, insulators, structures, foundations, earthing systems, and clearances. Repair work or replacement of components depends on their estimated lifetime which is usually decades. If structures are painted for corrosion protection, maintenance painting becomes necessary every 15 to 25 years and in case of Duplex coating every 35 to 45 years. This means that painting of steel towers is the maintenance measure with the highest frequency of all maintenance works.

9.1.5.3 Access roads

Access roads can be temporary or permanent; this depends on the agreement with landowners and or on legal prescriptions. In some cases access roads may have a secondary function (e.g. as fire corridors).

The material used for access roads is standard material for roadwork such as aggregate, sand, stones. In general no tarmac is applied. All these substances can be dismantled easily and can either be reused for other similar projects or can be recycled. After dismantling and re-cultivation no influences remain on the soil. In very sensitive regions synthetic material for access tracks can be used to reduce the pressure on sensitive surfaces. This material can be stored and reused for similar uses. If recycled, this needs to be carried out in special plants taking into account the properties of the material.

9.1.5.4 Soil protection

The protection of soil has a high value in most countries. In others, the following is demanded: no irreversible damage by any human activity, protection of watercourses, air and forests, prevention of continued sealing, decontamination, re-seeding, prevention of erosion and no compaction.

9.1.6 LCA Studies on OHL Components – Results of Analysis, Impact Assessment and Conclusions

9.1.6.1 Lattice Steel Tower

- Because of the large quantity of iron used in a lattice steel tower, the resources required for iron production such as coal for coke reserves and Fe reserves are consumed largely in the steel angle member manufacturing process as compared to resource exhaustion in the manufacturing processes of other parts of the tower.
- Concerning emissions to the air, the lattice steel tower manufacturing processes such as shearing, bending, chemical pretreatment etc., which are dealt with domestically (in Japan), have more influence on this area and this results in more domestic emissions of gas (such as CO_2, NO_x, SO_2) to air.
- The environmental impact from resource exhaustion could be largely reduced by the introduction of a recycling process although other environmental impacts, which are related to emissions to the air, do not seem to be reduced as much as resource exhaustion does.

9.1.6.2 Conductor

- In the manufacturing processes of ACSR, the manufacturing process of aluminium ingots has a dominant environmental impact.
- The environmental impact is not only related to ACSR manufacturing countries, but also related to outside countries in the world when the system boundaries include the extraction of resources and the material production.
- The recycling of conductors could significantly reduce the environmental impact.
- The environmental impact of transmission losses is greater than that of the conductor manufacturing process (they have about ten times greater impact than that of the manufacturing phase).

9.1.6.3 Insulators

More energy resources are consumed in the insulator manufacturing processes of porcelain disc insulators than in the raw material manufacturing process and that results in more domestic emission of gases (such as CO_2, NO_x, SO_2) to air as well as an increase in the environmental impact.

9.1.7 OHL LCA Studies

The conclusions in 9.1.3 may be noted and also the fact that the particular situation in each country must be considered.

9.1.7.1 154kV OHL Japan

Environmental Impacts caused from each component

- For gas emission related categories such as global warming, acid rain, etc., the conductor has more impact than other components due to the large amount of electricity consumption necessary for its production.
- With regard to resource exhaustion, the lattice tower has the largest impact because of its consumption of zinc and lead

Environmental Impacts Comparison between production and use (transmission losses)

- In all categories the use phase has dominant impact compared to the production phase. The ratio of production to use is about 1 to 9.

Influences of recycling processes

- Environmental impact does not decrease in proportion to the recycled material volume of removed components because additional energy is required for the recycling processes themselves.
- Aluminium recycling plays an important role in reducing environmental impacts in gas emission related categories.

9.1.7.2 1km 400kV OHL Denmark

In respect of the transmission and distribution of electricity, it is notably the grid losses that generate environmental impacts. In Denmark, electricity production is largely based on fossil fuels. If you exclude grid losses, only 0.3 per cent of the environmental impact is related to the physical parts of the transmission overhead lines (see Fig. 73, section 8.2.4). However, this share will increase as production changes from fossil fuels to renewable energy.

It can be seen from the study that foundations are the principal source of most environmental impacts across the range of impacts in the various categories. The production of cement, which is very energy intensive, and steel for the reinforcement of the foundations stand out especially. An important factor is the assumption that the foundations cannot be recycled.

The conductors are major components in the overhead line and it is assumed that 90 per cent of the materials will be collected and recycled. In this way, the overhead line impacts are credited with the energy-intensive processes in connection with the production of aluminium and steel

The towers are the largest metal components. Like the conductors, the towers are expected to be dismantled and reused in new products. Here too, the recycling process is credited to the towers.

Around 75 per cent of the environmental impact is related to the foundations and the towers.

Transport included all transport from the factory to the place of erection, haulage vehicles, cars and helicopters for inspection and haulage vehicles for dismantling. Finally, transport for recycling has also been included. Transport has a major impact in some impact categories.

9.1.7.3 Comparison of Danube Tower to new design

The foundation of a Danube double circuit tower uses 36 per cent more concrete than the new single circuit design of tower. The concrete cannot be recycled and the Danube tower therefore features the largest environmental impact in this category.

If volume waste is disregarded, the new design tower which is single circuit will have a larger environmental impact than the Danube tower in the other categories. The main reasons are that stainless steel has been used in the construction of the head of the design tower and that a 150 kV PEX cable is needed to make the solution as good as the Danube tower solution.

A comparison between the two types of towers will favour the type of tower that carries most circuits, that is the Danube tower.

The estimated lifetime of the overhead line has a significant influence on the impacts. If you double the lifetime, the impact tends to be reduced by 40-50%.

9.2 Recommendations

- Life Cycle Assessment studies for overhead lines and overhead line components should be performed using the ***ISO 14040 Environmental Management - Life Cycle Assessment*** series. The goal and scope of any study, be it environmental reporting, product improvement or product comparison should be clearly set out, including identification of the intended audience.
- The product system and its boundaries must be properly defined and modelled. These will depend on whether the overall grid, an overhead line or overhead line components are being studied. This will also apply to the choice of functional unit and a relationship can be established between different units depending on the system boundaries.
- No matter which system is going to be analysed and how it is modelled, the allocation criteria should always be similar. Regardless of which product system is chosen, the representativeness of the population studied is one of the major requirements, if the results of the LCA study are to be taken seriously.
- With regard to Life Cycle Impact Assessment the choice of the impact categories to be considered should be justified in relation to the goal and should be initially included in the scope of the LCA study. The choice of characterisation indicators is critical at this stage.
- An LCA software package appropriate to the country or region in which the assessment is being performed should be used.
- The comparison between different LCA software packages shows that consistent results cannot be obtained, and there is little meaning in comparing the final values of results derived from several different LCA software packages. Therefore taking differences between software packages into consideration, it is recommended that impact assessment comparison (such as a comparison between an original product and an improved one) should be carried out using the same LCA software.
- The overview of overhead line components showed that well established methods exist for recycling of some of the major overhead line components particularly steel towers and conductors. These methods should be availed of and efforts increased to recycle all overhead line components.
- Efforts should be made to keep the duration of overhead line construction to the minimum as significant environmental impacts can arise at this stage. It is recommended that Environmental Management Plans should be developed and used. If required by the authority or by the landowner, access roads should be removed and recycled. Maintenance activities should be organised and scheduled to eliminate or minimise environmental impact particularly painting of towers.

- The results of actual LCA studies carried out on some of the principal overhead line components lead to the following recommendations
  - To reduce environmental impact, especially to reduce resource exhaustion impact, it is strongly recommended that lattice steel towers should be recycled. It could reduce the amount of iron reserves consumption as well as zinc reserves consumption. In the case study, it was presumed that zinc is recycled; however recycling zinc is not as common as recycling steel. The extent of zinc deposits in the world is much less than those of iron and taking this situation into consideration it is also recommended that zinc recycling processing should be widely adopted
  - To reduce environmental impacts, such as gas emission related impacts as well as resource exhaustion impact, it is strongly recommended that conductors should be recycled. It is commonly known that the energy required for recycled aluminium is about 3% of original aluminium production. The electrolysis process to extract alumina from bauxite for original aluminium production needs a large amount of electricity, while the aluminium recycling process basically consists of melting and moulding processes, which need less energy than the electrolysis process.
  - Another way to reduce environmental impact is to reduce transmission losses. In this respect the development of low resistance conductor seems an effective way that could be recommended. Upgrading to a higher voltage power system may also seem to be effective; however a more comprehensive analysis of the whole power system would be needed to draw this conclusion.
  - With regard to insulators only a small percentage of removed insulators are experimentally recycled as construction materials and a porcelain insulator recycling system is not fully established. Knowing that more energy is consumed in the insulator manufacturing processes of insulators than in the raw material manufacturing processes, establishment of the reuse of removed insulators as value added materials is desirable since material production itself for insulator production is not so energy consuming and it seems important to effectively reuse insulators which have already consumed energy in their manufacturing process.
  - Another approach to reduce environmental impacts might be to extend the function as insulators as long as possible. In this respect development of efficient and reliable diagnostic methods as well as life span extension technology is recommended.
- The recommendations from the study on a 154 kV overhead line section in Japan reinforce those noted above.
  - To reduce environmental impacts caused from OHLs (excluding power transmission losses), recycling aluminum of the conductor seems the most effective way and it is recommended that efforts should continue in promoting aluminum recycling.
  - Furthermore in terms of natural resource preservation, recycling lattice towers especially zinc recycling, is effective. However zinc-recycling systems have not been established sufficiently compared to steel recycling systems, this might be another area to be focused on.

  - Concerning transmission losses, the development of low resistance conductors seems an effective option to recommend. Upgrading of OHLs to higher voltage ones might be another option, however further more detailed LCA studies, which would cover the broader power system, would be needed to conclude this.
  - It should be noted that this study was conducted based on the data obtained mainly in Japan and environmental impacts stemming from power transmission losses are largely influenced by its power generation sources. Knowing from the results of the study that power transmission losses have major environmental impacts, it is recommended that the situation (such as power generation sources) in each country should be reviewed when interpreting LCA results in each country.

- These are complemented by the recommendations from the Danish study on 1km of 400kV OHL which also included a comparative study on the use of new structure designs (single circuit) as against the traditional double circuit lattice steel tower design.
  - Using LCA studies to reduce the environmental impact requires an overview of the entity that the LCA study forms part of. This is particularly the case if a utility is willing to invest money in order to reduce the environmental impact. Otherwise, it is very likely that investment would not be made efficiently.
  - Technically, a reliable way to reduce the environmental impact from overhead lines is to ensure that a transmission tower is designed for two or more circuits. In this way the environmental impact related to foundation and towers tends to be minimised per 1 kWh of electricity transported. New foundation design and construction could be another effective way to minimise the environmental impact.
  - LCA studies of components in the power system are still evolving. As far as models for the transmission grid are concerned results from the studies can be used as a supplement in evaluation of, for example, different types of towers or foundation technologies.
  - The lifetime of the different components of the overhead line should be estimated individually

Life Cycle Assessment is a very valuable tool for overhead lines engineers, planners and utilities to assist in the evaluation of the impact or interaction of overhead lines and the environment. It can be used and developed across a range of applications from environmental reporting to product improvement and comparison. However it should be noted that its use has some restrictions. LCA does not prioritise impacts; there is no differentiation between local impacts and those diluted in time and space. For instance it is not possible to differentiate between a large pollution over a short time period and smaller pollution over a longer period. It should also be noted that other tools and techniques exist to assess and reduce overhead line impacts on the environment and LCA results should always be evaluated in this broader context.

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APPENDIX

Glossary of LCA terms and definitions

The following definitions for the principal LCA terms, from the ISO 14040 series, are given for convenience.

Allocation

Partitioning the input or output flows of a unit process to the product system under study.

Characterisation Factor

Factor derived from a characterisation model which is applied to convert the assigned LCI results to the common unit of the category indicator.

Comparative Assertion

Environmental claim regarding the superiority or equivalence of one product versus a competing product which performs the same function.

Elementary Flow

- Material or energy entering the system being studied, which has been drawn from the environment without previous human transformation.
- Material or energy leaving the system being studied, which is discarded into the environment without subsequent human transformation.

Energy Flow

Input to or output from a unit process or product system, quantified in energy units

Environmental Aspect

Element of an organisation's activities, products or services that can interact with the environment.

Functional Unit

Quantified performance of a product system for use as a reference unit in a life cycle assessment study.

Impact Category

Class representing environmental issues of concern to which LCI results may be assigned.

Input

Material or energy which enters a unit process.

Note: Materials may include raw materials and products.

Interested Party

Individual or group concerned with or affected by the environmental performance of a product system or by the results of the life cycle assessment.

Life Cycle

Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal.

Life Cycle Assessment

Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life Cycle Impact Assessment

Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system.

Life Cycle Impact Category Indicator

Quantififiable representation of an impact category.

Life Cycle Interpretation

Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations.

Life Cycle Inventory Analysis

Phase of life cycle assessment involving the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle.

Life Cycle Inventory Analysis Result

LCI Result

Outcome of a life cycle inventory analysis that includes the flows crossing the system boundary and provides the starting point for life cycle impact assessment

Output

Material or energy which leaves a unit process

> Note: Materials may include raw materials, intermediate products, products, emissions and waste.

Practitioner

Individual or group that conducts a life cycle assessment.

Product System

Collection of materially and energetically connected unit processes, which performs one or more defined functions.

> Note: In this International Standard, the term "product" used alone includes not only product systems but can also include service systems.

Process Energy

Energy input required for a unit process to operate the process or equipment within the process excluding energy inputs for production and delivery of this energy

Raw Material

Primary or secondary material that is used to produce a product.

System Boundary

Interface between a product system and the environment or other product systems.

Transparency

Open, comprehensive and understandable presentation of information.

Unit Process

Smallest portion of a product system for which data are collected when performing a life cycle assessment.

Waste

Any output from the product system which is disposed of.