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Legislation using LCA concerning Aluminium

Report

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Preface

This document is an analysis document. Four cases of legislation using LCA's concerning aluminium have been analysed. After discussion of this analysis a communication document has been written that the Aluminium Industry can use for the discussion with politicians about this item.
It will be decided by the EAA whether and how this discussion will take place.

Contents

Summary

Introduction

The use of LCA's to support policy making and legislation is expected to increase. Despite the fact that the LCA methodology is not designed for legislative purposes, it can be considered inevitable that LCAs will be used. It's actually not designed because different scientific approaches of some LCA aspects are possible. These different approaches can lead to totally different results. It will be used because politicians want to make decisions considering environmental, social and economical aspects.

EAA commissioned CE to analyse four specific cases where an LCA was used for legislative purposes: an LCA on packaging in Germany, an LCA used for taxation of packaging in Denmark, an LCA framework used in the Dutch Building sector and a Swiss LCA on building products.

Aim of the project

The aim of the project is a balanced use of LCA's in legislation concerning aluminium by politicians and policy makers.
The objective of this project is to identify the starting points, assumptions and choices that may have a decisive influence on the outcome of an LCA ('critical points') for aluminium specifically and to enable the EAA to draw up a set of recommendations that can aid politicians and policymakers when confronted with LCA's.

This document presents the results of an in-depth analysis of the cases and the lessons that can be learnt from these with respect to legislation using LCA's. A communication document has been written using this analysis. This document can be used in the discussion with politicians and policy makers.

The analysis

The analysed four cases are:

1 The Danish packaging LCA that is used for the tax law.
2 The German Packaging LCA, UBA 2.
3 The Dutch LCA for window frames as an example within the MRPI system.
4 The Swiss LCA for facade panels.

The selection of the most relevant aspects for LCA's concerning aluminium was made using the following criteria:

1 Key aspects of the general LCA framework.
2 Aspects or parameters that show a large variation.
3 Aspects that were criticised by the aluminium industry or other stakeholders. This information was obtained from interviews with representatives from the aluminium industry.

The analysis of these cases led to the conclusion that six aspects of an LCA can have and actually had a major influence on the outcome of the LCA.
These aspects are:

1 The *political context of the LCA*. This includes the reason why an LCA is made, the actuality of the political discussion and the diversity of opinions. For example: The reason in Denmark to commission the LCA was to establish the environmental profile of packaging materials with the objective to use these for the Tax Law. This aim led to an incorrect func-

tional unit and weighting of the analysed impact categories. The German LCA was used after it was finished for legislative purposes, although this was not the initial objective of the LCA.

2 The *management of the LCA process and stakeholder participation*. Aspects of this process are the involvement of the industry and other third parties and a critical review. It became clear that when a critical review and the involvement of the industry are missed, ISO rules are not always followed correctly and mistakes are made.

3 The start of an LCA with the *goal and scope definition and the functional unit*. As the Danish case shows using an incorrect functional unit leads to incorrect results.

4 The *used electricity scenario(s).* Because in the primary production of aluminium a lot of energy is used, the use of a wrong energy scenario can have a major effect on the result of the LCA. Mostly (except in the Danish case) the used electricity scenario is the scenario used in the EAA environmental profile report. In the sensitivity analyses, however, the used energy scenarios show large discrepancies.

5 The *used method(s) for the crediting of recycling*. In the Key features document methods for crediting recycling are recommended. Other methods are however possible and are used in the LCA's, especially in the sensitivity analysis. Each method has its own scientific value. Each method can lead to another result of the LCA and the results can differ enormously from each other. Each result however is scientifically correct. This causes problems in interpretation of the results of the LCA. Especially in the sensitivity analyses of the analysed LCA's different methods for crediting recycling have been used.

6 The *weighting method*.

Conclusions

Managing the LCA process: Stakeholder participation

Involvement of the industry during the whole process of the LCA proves to be very important. The Danish case learns that involvement before the LCA is started is crucial. The definition of the goal and scope of the LCA and the functional unit as a result of this definition caused most of the problems the industry has with the results of the LCA. The German case learns the relevancy of being alert on the policy discussions about packaging.

Especially when a discussion has a high political profile, diverging opinions and a high risk, it is crucial that the aluminium industry is involved from the very beginning, before an actual LCA is started. The involvement should continue during the whole process of performing the LCA, the interpretation of the results and the use of the results.

The Dutch and Swiss case learn that it proves to be effective to develop a general framework for the LCA's for a group of products. Within this framework agreements can be made about important aspects such as the energy scenario, recycling, functional unit, the database to be used, etc. This avoids discussions when the LCA's are conducted and ensures comparability of the outcomes. In the Danish case and the German case there was no such framework. In the Dutch case the framework was the result of discussions with LCA specialists and Industry. In the Swiss case the industry was successful in changing the framework with respect to recycling. The aluminium industry should support such developments of framework methodologies for product groups and support standardisation.

If politicians want a (tax) law, they will make one. Realising this the industry can try to influence this process with for exemple to propose parameters the tax will depend on. In the Danish case the tax was based on the environmental profile that resulted from the LCA, multiplied by the weight of the packaging material. As the environmental profile is fixed, this tax only stimulates weight reduction. Propositions for other incentives in the system like recycling percentage could have given more possibilities for the industry to hold the initiative in influencing the tax law.

Overall conclusion on this topic: be alert and proactive.

LCA methodology: inventory aspects

The way an LCA is performed determines the result of an LCA. Choices and assumptions made regarding a number of key aspects can be decisive for the outcome. The Aluminium industry must make clear to politicians this can have a major effect and that, because of it, it is crucial to follow the ISO standards.

The first aspect is *the functional unit*. This must be chosen properly and in accordance with the standards. Actually the functional unit of a packaging should also hold aspects as protection to decay of the packaged product and offering the desired quantity. Such broader functional units have more possibilities for the industry to improve the environmental profile. It could be profitable for the industry to try to broaden the functional unit with these aspects.

The *energy scenario* for the production of aluminium can have a major effect on the result. It must be made clear what realistic scenarios are.

Crediting of recycling can have a major effect on the result too. It must be made clear that there are several methods that are scientifically correct but can lead to a totally different result of the LCA. Each result is correct from a scientifically perspective. It's not just a range as result of a sensitivity analysis, from which you can pick the average.

A *critical review* is obligatory, also when the LCA practitioner is very experienced. The Danish case learns that failures in figures, functional unit, energy scenario and sensitivity analyses are easily made.

Two recommendations can be formulated which can be considered to put in the EEA Key Features document [20] or in the EAA Environmental Profile report [21].

- The first is to present a range of emission profiles in the environmental profile report, which LCA practitioners can use for the sensitivity analysis. In the Key Feature document this range can be advised. It is better to present a range, otherwise LCA practitioners will construct a range themselves.
- The second is to advise which crediting methods should be used in the sensitivity analysis.

LCA methodology: weighting

Although weighting in comparative LCA's disclosed to the public is not allowed in ISO standards, politicians will do it or ask the LCA bureau to do so. Politicians prefer to have a limited number of indicators for the assessment of the environmental effects. Otherwise it is almost impossible for them to make decisions when social, economical and environmental aspects have to be taken in account. Realising that weighting is inevitable it is advisable for the industry to be pro-active in developing a weighting method (or a set of weighting methods) that is supported and acceptable by scientists and politicians. It is advisable to co-operate on this topic with other industrial sectors like the steel industry and the plastic industry.

Recommendations

On basis of the in-depth analysis the following recommendations are formulated. Each can be assigned to a specific target group to which the recommendation is directed. Three target groups for the EAA are distinguished.

1 The Aluminium Industry.
2 The policymakers and politicians.
3 The LCA practitioners.

The recommendations for the Aluminium Industry are internal. The recommendations for the last two target groups are important for external communication, each requiring a different communication style. The communication to policymakers and politicians are more focussed on the LCA process and to the practitioners more on specific LCA details. Here we mention the recommendations for each target group.

Recommendation for the Aluminium Industry itself

- The Aluminium Industry should initiate a monitoring system to identify possible LCA studies commissioned by politicians/policymakers and linked to possible legislation.
- Present a range for different energy and allocation scenarios in the environmental profile report.
- *Murphy's law: If something can go wrong it will go wrong.* Rephrase: if (politicians think) an LCA can be used for legislation it will be used.
- Be aware that weighting or similar simplifications may be done in the decision-making process.

Recommendations for external communication with politicians and policymakers

- Any commissioned LCA study should be done according to the EN ISO 14040-series standards.
- A critical review panel should be involved at the very early stage of the LCA study and the Aluminium industry should be invited to participate.
- Weighting is not allowed in comparative LCA's disclosed to the public by the EN 14042 standard. An LCA should end with a certain amount of indicators but not with one figure.
- The functional unit should be properly chosen.
- The proper method should be used to take into account the Aluminium recycling abilities.
- Consensus on all key aspects should be reached before the LCA study starts.

Recommendations for external communication with LCA practitioners

- Weighting is not allowed in comparative LCA's disclosed to the public by the EN 14042 standard. An LCA should end with a certain amount of indicators but not with one figure.
- The functional unit must be properly chosen.
- The EAA energy model and the generic data as collected by EAA should be used.
- Aluminium recycling should be considered and only Aluminium losses within a life cycle should be taken into account.

1 Introduction

1.1 Reference of this project

Producing a life cycle analysis (LCA) is more and more common practice. Standards and normalisation for LCA's are being developed. In the document 'Key features how to treat aluminium in LCAs' the Aluminium Industry describes how an LCA has to be performed using ISO 14040 series. The standardisation of LCA is also the moment at which legislation using LCA will become possible and can be expected. This evolution to legislation using LCA is of importance for the Aluminium Industry. The primary aluminium production is energy demanding and the industry is held responsible for the related environmental effects. The industry is aware of this evolution. In the BDI position paper 'The Political Role of LCA's' the Federation of German Industries puts forward theses on the role that LCA's play in the political development.

Despite the standards and normalisation of LCA's discussions remain possible about the starting points and assumptions. Using other starting points or assumptions can have a major effect on the results of an LCA. Even within the ISO framework LCA results can differ within a broad range. Besides that, in practice not all LCA practitioners work in full accordance with the standards. In case an LCA is used for comparing products[1] and the results vary within a broad range, disputable conclusions can easily be drawn. When used for legislative purposes this can be disadvantageous to some products.

The starting points and assumptions can depend on political goals. These goals must be addressed and effects on the results of the LCA must be made clear. Unclearness can lead to mistrust. When the results of an LCA are positive and not in accordance with their pre-assumptions, NGO's mostly mistrust these. When the results are negative the industry mistrusts the correctness of the method.

For not-insiders an LCA is a black box and discussions about standards, starting points and assumptions are unclear. Between politicians / policymakers and LCA specialists/researchers there is a gap. The politicians and policymakers are not interested in scientific discussions about assumptions and starting points. They are interested in clear results. Environmental effects are just one of the aspects (besides social and economical aspects) in decision making. Up till now LCA specialists and researchers have not communicated sufficiently about the influence of using other starting points and assumptions and the limitations of LCA's. For the industry itself this communication is difficult because it has an interest in the outcome of an LCA.
Clearness about the standards and limitations of an LCA but also clearness about effects of using other starting points can help to narrow the gap.

[1] An important question for using LCA's is for which goal one wants to use them. Possibilities are:

- Identification of major environmental effects in the production chain. An LCA can be very helpful to improve the environmental impact of a product chain and to communicate about this.
- Identification of options for improvements.
- Comparing products (aluminium cans against PET bottles).

Discussion about starting points cannot be prevented but politicians and policymakers at least must be made aware of the influence on the results.

EAA commissioned CE to analyse four specific cases where an LCA was used for legislative purposes: an LCA on packaging in Germany, an LCA used for taxation of packaging in Denmark, an LCA framework used in the Dutch Building sector and a Swiss LCA on building products.

1.2 Aim of the project

The aim is the balanced use of LCA's in legislation for aluminium by politicians and policymakers.
The objective of this project is to identify the starting points, assumptions and choices that may have a decisive influence on the outcome of an LCA ('critical points') for aluminium specifically and to enable the EAA to draw up a set of recommendations that can aid politicians and policymakers when confronted with LCA's concerning aluminium.

1.3 Method

Four specific LCA cases are analysed to assess the effects from certain assumptions and starting points on the outcome of the LCA.
- We analysed the LCA's focussing on the most important aspects within the LCA framework. What kind of conclusions can be draw from the discussions in the cases?
- We also analysed the political context of the cases to assess the influence on the LCA results. The political context determines the reason to perform an LCA, the political goals, the political discussion around the object of the LCA, and what is done with the result afterwards. The question is what lessons can be drawn from this political context?
- We also focussed on the management of the LCA project to see what influence it has on the results. The leading questions are: How was the process managed, were stakeholders consulted, which stakeholders were consulted, was a critical review carried out, by what parties (experts or stakeholder panel)?

For each case a representative from the aluminium industry was appointed to provide the necessary background information[2]. Also, a steering committee including EAA members was appointed to monitor the progress of the study (see Annex C).

This document presents the results of the case study analyses: the lessons learnt and the subsequent recommendations. In the next step these are transformed to a communication document that can be used in discussions with politicians and policy makers.

[2] Jim Hansen of Aluminium&Miljø from Denmark. Hans-Jurgen Schmidt, VAW AG, Germany, K. Buxman, ALCAN, Swisterland, and Niels Ruyter, Aluminium Centre The Netherlands.

1.4 Follow up of the project

In addition to the final “political” document mentioned above, recommendations will be formulated for an external discussion with stakeholders. At the end of the project the strategy how to communicate to the politicians will be decided on the top level of the Aluminium for Future Generations campaign:

- Discussion per country and/or discussion on EU level.
- A seminar, workshop and/or round table discussions.
- Discussion with NGO's.

1.5 Set up of the report

This report is structured in the following way.

First, we introduce the selected case studies by providing some background information about the political context (Chapter 2).
Next, we select the aspects that need to be considered in the analysis of the case studies. These are derived from the general LCA framework. A further selection, identifying the most relevant aspects is made on the basis of the discussions with the stakeholders about the LCA’s (Chapter 3). These key aspects are then discussed in more detail in Chapter 4 and Chapter 5. Here the conclusions and recommendations are presented related to each aspect. In Chapter 6 the focus is more specifically on the LCA process.
Conclusions and recommendations are then presented in Chapter 7.

The factsheets of the four cases are publised in a separate annex report.

2 Background and political context of the cases

2.1 Introduction

This Chapter introduces the four case studies where an LCA was used for legislative purposes: an LCA on packaging in Germany, an LCA used for taxation of packaging in Denmark, an LCA framework used in the Dutch Building sector and a Swiss LCA on building products.

Our focus here is on the backgrounds and the political context within which the LCA's are positioned. A detailed description of the LCA process during the time period of the actual LCA project is given in Chapter 6.

2.2 Backgrounds and political context

2.2.1 Danish case: packaging materials

The "Danish case" is an LCA carried out to support an amendment of the Danish Tax on packaging materials.

A new Tax Law came into force on 1 April 2001 in Denmark. This law allowed for taxation of packaging, both on weight and on environmental impact. Before, packaging was already subject to taxation, but this was based on weight alone. In 1998, a proposal was submitted in Parliament to further differentiate the weight-based tax rates to include environmental impact. The aim was to improve of the environmental impact of the tax and also *to obtain a larger degree of competitive equality between different applications of materials.*[8]

To support the amendment of the packaging tax, the Environmental Protection Agency (EPA) of Denmark commissioned a study to assess the environmental impact of the packaging materials. A Life Cycle Assessment (LCA) was carried out for this cause [7][3]. The LCA served as the basis for the actual Tax Proposal by the Danish Environmental Protection Agency (EPA) [8]. The Proposal describes a method that rates different packaging materials according to the environmental impact. The EPA Proposal was initially made public in July 2000. As a result of the comments from industry and the public interest in the issue, the Danish Environmental Protection Agency decided to revise the original version. The revision was published in August 2001.

We analysed both the LCA and the EPA Tax Proposal.

The whole Tax Law is under great scrutiny in Denmark. The aluminium industry states that the present tax system does not guaranty that it will be effec-

[3] Prior to the Tax amendment another LCA on packagings was published, also commissioned by EPA: the Chalmers study (1997): "LCA for packaging systeem for beer and soft drinks" (1997) by Chalmers Industritechnik (CIT), Sweden and Institut for Productdevelopment (IPU), Denmark. This LCA is **not** the LCA supporting the Danish Tax system and it plays no explicite role in the discussions about the Danish Packaging Tax. It is referred to only marginally.

tive in the overall aim to reduce the amount of new packaging materials (in weight) in the market. It will more likely lead to suboptimalisation.
Also, the industry fears that the present Index and the possibility of comparing and ranking the materials with the Index can be (mis)used in the public communication. Already, the paper industry in Denmark claimed that paper packaging is environmentally superior than other materials using the tax Index as an argument. This led to a heated discussion in the Danish (packaging) media, where in the end it was agreed upon that this was not allowed.
The European aluminium industry (EAA) filed a formal complaint at the European Committee against the Danish Tax Law on Packaging at 23 January 2001 (see below).

The LCA were performed in accordance with the specifications of the EDIP methodology[4]. The authors of the LCA state that the EDIP method follows the ISO standards on all mayor points.

2.2.2 German case: beverage packaging

The “German case”, commonly referred to as the UBA II is a LCA on beverage packaging. It was commissioned by the Umwelt Bundes Amt of Germany (UBA) in 1998 with the purpose to support the decision making process for the German environmental policy. This policy aims to reduce the environmental impact of packaging, either by implementing legislative measures, or by stimulating technological innovations for packaging. In the past, the primary focus of the policy was on reducing packaging waste. The aim is to broaden the scope including the environmental aspects across the life cycle of the packaging. The LCA is seen as a suitable tool facilitating the discussion on packaging.

The complete study consists of two parts, Status-Quo-Analysis (Part I) and Future Scenarios (Part II). The study analysed here is the Status-Quo-Analysis, or **UBAII-study**. The second part will be concluded in the near future.

Of the LCA the inventory and impact assessment phases were conducted by a project team consisting of Prognoses (Basel, Switserland) IFEU-Institut (Heidelberg), Gesellschaft fur Verpackungsmarktforschung (GVM, Wiesbaden) and Pack Force (Oberursel). The interpretation of the results was conducted by the Umwelt Bundes Amt.

In previous years, studies were also commissioned by UBA on methodological aspects, practical assumptions and starting points in LCA’s [Projektgemeinschaft Lebenswegbilanz, 1992], on beverage packaging for beer and fresh milk [kobilanz Getränkverpackungen für Bier und frischmilch 1995]. Also relevant is the “Handreichung Bewertung in kobilanzen”. This Guide, an initiative of the Umweltbundesamt presents a method that uses for ranking between different categories of environmental impacts.

4 (UMIP: "Udvikling af Miljøvenlige Industriprodukter") EDIP is an abbreviation for "Environmental Development of Industrial Products", a 4-year research project funded by the Council for Recycling and Clean Technology amongst others.

The LCA was conducted in accordance with the ISO standards 14040 to 14043. An external expert panel carried out the critical review[5].

2.2.3 Dutch case: building products MRPI

The “Dutch case” is an LCA on aluminium windowframes conducted by the Aluminium Centrum of The Netherlands (Niels Ruyter) and commisioned by the VMRG, representing the windowframes sector. It is an illustration of the framework of the MRPI that has been developed in the Netherlands to assess the environmental impact of building products.

Since the nineties the national environmental policy plans emphasised the need of product-oriented environmental policy [e.g. VROM, 1993]. Sustainable building was part of this new approach.
At the time little was known about the environmental impact of the different materials and the different ways of construction. The Dutch Foundation for Experimental Housing (SEV) has made a list of environmentally undesirable building materials. This list was very simple and easy to use and a lot of municipalities started using these so-called SEV-lists. The manufacturers of construction materials, as well as the government and the SEV, found that these lists were unrepresentative for the real environmental impact or construction materials in specific situations. To replace these rigid lists the building materials sector in the Netherlands (NVTB) started the MRPI: Environmentally Relevant Product Information.
The purpose of MRPI is, to present product related environmental information in a standardised matter on an MRPI factsheet. This information should also be calculated according to standards. To set these standards the MRPI commission, with the involved industrial parties, set up a standard and a manual for MRPI. Starting point for this manual was the LCA manual from CML [1992].

The MRPI’s are acceptable to the industry, they are credible and they can take the environmental performance of materials in different situations into account, because:

- The producer/manufacturer of the product(s) is responsible for performing an MRPI.
- The MRPI is to be verified by an accredited LCA consultancy.
- The MRPI is only valid for the specific, described material or function.

The MRPI’s inform interested parties about the environmental performance of construction materials in functional units or as material. This means that if municipalities set certain sustainability requirements for building projects, the constructors will have to analyse all the MRPI’s and calculate the overall environmental performance of a building or building project. To aid this calculation different software has been developed, of which EcoQuantum seems to be the best accepted at present. This program is based on the information of the MRPI and more general environmental database information (like Buwal) and aids constructors, consultants etc. by calculating the environmental performance of the materials.

To stimulate and regulate sustainable building the Dutch government made legislation concerning the energy performance of buildings during the phase of usage: the energy performance standard. Now the Dutch government is

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[5] Mrs. De Groot-van Dam (TNO, Delft), Dipl.Ing. Gensch, Prof. Dr. W. Klöpffer, Dr. H.J. Klüppel.

working on regulation concerning the material related environmental performance of buildings (MMG). The design of this MMG is, in the Dutch tradition, discussed with the involved parties and has not been finalised yet.
Now pilots are testing the concept format for MMG. Issues that still need to be solved before finalising and implementing regulation concerning the MMG are:

- The level of aggregation. Should it stop at the level of CML-themes or aggregate it to 5 or even one indicator?
- The relationship with the phase of use. Should the EPN be integrated into the MMG or should they coexist?
- Allocation methods. Where are system boundaries set? How do you allocate recycling? Etc.

These will be political choices. If MMG will be implemented therefore depends on the political will and courage to do so.

Relation to ISO
MRPI is based on the ISO standards and the methodlogy of CML 1992. Contradictory to ISO it does involve weighting. In adherence to the MRPI standard in this study the environmental themes are normalised based on the world emission data (CML) for the environmental measures. There is no reason given for choosing this method in the MRPI standard. In the MMG the weighting step is in discussion. A possible outcome is that no weighting will been done.

2.2.4 Swiss case: building products

The “Swiss case” is an LCA carried out by ALCAN on façade sheet sheets for buildings. The study is meant primarily as an in-company study on the basis of which ALCAN can determine how environmental impact related to production of the façade sheets can be reduced.
The case was selected because it illustrates a specific methodology for recycling which had been subject of discussion in Switzerland.

In Switzerland legislation was adopted that is aimed at reducing environmental impact related to use of buildings and to the materials incorporated in buildings.

As a part of this policy each producer of building components has to give information of environmental data of his product, ("Deklarationsraster") including the "grey energy". The 'grey energy' is defined as the amount of energy from fossil or nuclear origin consumed in the production of the materials and components. A guidance document how to calculate the grey energy for aluminium has been elaborated by an independant consultant, the Büro für Umweltchemie, Zürich, based on the total energy (renewable and non-renewable) needed to produce primary aluminium from bauxite. A lower value is only permitted if the product has a certain content of recycled aluminium.

Two types of methods were applied to determine the recycled material content[6]. Both methodologies showed unfavourable results for aluminium products and therefore for the market perspectives for aluminium producers operating in the building component market. After discussions with the aluminium industry in Switzerland and after publication of the ISO 14040 LCA framework the allocation methodology for recycling had to be reviewed. The aluminium industry in Switzerland, headed by the alu.ch has started a camaign to calculate the grey energy based on the guidance given by ISO 14041 and the "Key features document" [20] (see Chapter 4.4). This approach has been supported by the EMPA (Eidgenössische Materialprüfanstalt) which has a leading position in Switzerland on LCA issues in the building sector. On the other hand, other consultants such as the Büro für Umweltchemie, Zürich are not prepared to revise its guidance document how to calculate the "grey energy". Presently, the discussion is on-going.

The LCA considered is conducted using this allocation methodology for recycling.

6 In the first methodology recycling credits are only given on the input side, considering only the recycled material used in the product put on the market and totally neglecting the end-of-life phase in the life cycle of the product. In the second methodology recycling credits are given only in case recycling of the considered product in its end-of-life phase results in closed loop recycling, in other words when the produced secondary raw material is recirculated to the original product system.

3 Identification of major LCA aspects for aluminium

3.1 Introduction

In this chapter the major aspects of LCA's concerning aluminium are identified. These are derived from the general LCA framework and are selected on basis of the influence on the outcome of the LCA. A further selection, identifying the most relevant aspects is made on the basis of the discussions with the stakeholders about the LCA's.

3.2 Selecting key aspects from the LCA framework

The LCA methodology is described extensively in many documents. It is not our intention to double this work here. Instead, we will focus only on the general LCA framework and highlight the most important aspects. In the figure this LCA framework is illustrated. This LCA framework will also serve as a framework for the analysis of the four cases.

What is an LCA?
An LCA or Life Cycle Assessment is a scientific tool for the evaluation of environmental effects of products or services throughout its complete life cycle. Literally: "from cradle to grave." This involves the extraction of raw materials, refining, fabrication transportation, use, recycling and disposal, both of the product and the energy and ancillary materials supplies.

ISO standards
The LCA methodology is standardized in the internationally accepted EN-ISO 14040 series, accredited by the European Committee for Standardization. These standards reflect the state of the art methodology of the LCA. These describe the general framework and requirements for carrying out an LCA[7].

One specific set of requirements we mention here. These concern **"comparative assertion disclosed to the public"** i.e. a study made public comparing different materials or products claiming that a certain product is environmentally favourable. In those cases the following elements are mandatory in an LCA:

- A critical review of the comparability of the systems by a panel of concerned parties[8].
- An impact assessment[9].
- A third party report[10].
- A detailed sensitivity analysis[11].
- Weighting or aggregation of different impact categories is not allowed.

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7 ISO 140 40 Principles en framework; ISO 140 41 Goal and Scope Definition and Inventory Analysis; ISO 140 42 Impact assessment; ISO 140 43 Interpretation.

8 (ISO 14040 §5.1.2.4 en §7.3.3).

9 (ISO 14040 §5.1.2.4).

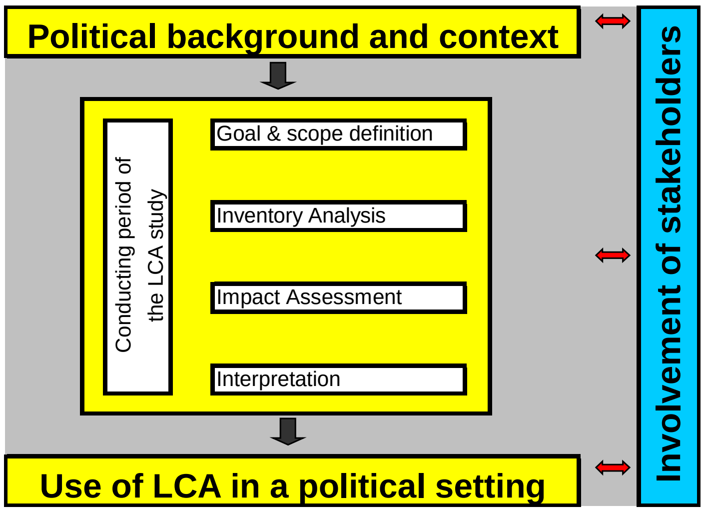
10 ISI 14040 Chapter 6.

11 ISO 14043 Chapter 6.3.

A typical LCA study comprises four distinct phases:
- Goal and scope definition: here the products, the reasons for carrying out the study and the intended audience are defined. The scope is the detailed technical description of the "product system".
- Inventory Analysis: (LCI) comprises the quantification of the materials and energy used and the emissions and wastes that arise.
- Impact Assessment (LCIA) comprised the quantification of the environmental impacts.
- Interpretation derives conclusions and recommendations.

For LCA's used for legislation the political setting is also of importance. These LCAs are commissioned by policymakers and the results are used and interpreted by the same or other policymakers. Also, stakeholders may be involved during the LCA process. In the figure the complete "LCA process" is visualised.

Figure 1 LCA context and process



Summarising, the following aspects are relevant considering LCA studies:
- The political backgrounds and context.
- The actual LCA with the distinct elements: Goals&scope, Inventory Analysis, Impact Assessment and Interpretation.
- The Use of the LCA results in the political setting.

These key aspects were analysed in detail for all the four case studies.

3.3 Selecting the most relevant LCA aspects for Aluminium

In every part of the process - the political background and context leading to the commissioning of an LCA study, the LCA conduction period and the phase where the LCA results are used in a political setting – there are major aspects that may influence the LCA outcome decisively.

A further selection of the most relevant aspects for LCA's concerning aluminium was made using the following criteria:
1 Aspects or parameters that show a large variation (with use of sensitivity analysis) and

2 Aspects that were criticised by the aluminium industry or other stakeholders. This information was obtained from interviews with representative from the aluminium industry.

In every case it became clear that the political context and the **reason to perform** the LCA had a significant influence on the LCA process and the outcome. Also, the way stakeholders participated during the LCA process proved an important parameters mainly determining the acceptance of the end results.

- In the Danish case the government wanted to base a tax law on the environmental performance of packaging materials. This was taken as a starting point for the formulation of the goal and scope definition. This affected the choice of the functional unit, which has a major effect on the result. These starting points of the ‘goal and scope’ also made it necessary to end the LCA with weighting between the categories.
- In the Dutch case preliminary simplified (SEV) preference lists triggered the industry to develop a standardised LCA framework for building products (MRPI). This LCA framework was made before starting the actual LCA's of the building material. Consequently, critical aspects are not a point of discussion when an LCA is performed.
- In the German case the use that politician wanted to make from the LCA results was different from the initial reason to perform the LCA. The hindlying objective – the use for policymaking – seemed to have influenced the development of a method used for the interpretation phase. This had a crucial effect on the outcome.

In the inventory phase of the LCA itself three aspect proved to be crucial for the result.

- The **goal & scope definition** and as direct result of it the functional unit.
- The choice of the **energy scenario.** The result of the study depends highly on the emissions of CO_2. This CO_2-emission is directly linked with the used energy scenario. It makes quite a difference whether a scenario with only fossil fuel is used or a scenario with a mix of hydropower, nuclear energy, natural gas and coal is used. When 50% hydropower is used and 50% coal the CO_2 emission of the Aluminium production is 50% less comparing with the use of only coal. It seems that in the Danish case a not correct scenario is used with major effects on the result of the LCA.
- The choices made regarding **credit for recycling.** Several methods are equally valid from a scientifical viewpoint. However, each method has an outcome that can differ much from another one. Because in the cases different methods are used, it was clear for us that we had to analyse this aspect.

Another very important aspect – alsways leading to much discussion- is the **weighting procedure.**

Summarising, six key aspect were identified:

1 The reason for the commissioner (policymaker) to perfom an LCA.
2 The choice of a functional unit.
3 The choices made regarding the energy scenario.
4 The choices made regarding recycling.
5 The choices made regarding the weighting procedure.
6 The involvement of stakeholders (during the LCA process).

In next chapters these aspects will be discussed in more detail. Other aspects, such as system boundaries or the data quality proved less relevant.

Either, because in none of the cases the stakeholders perceived these aspects as problematic, or because the aspect did not influence the outcome of the LCA decisively. These less relevant aspects are put in a matrix, which you can find in the appendix A.

4 Inventory aspects with major influence

4.1 Introduction

As stated in Chapter 3 there are three aspects in the inventory phase which can have a large effect on the results of an LCA: the goal and scope definition (functional unit), the energy scenario's and the recycling. In this chapter we will discuss these aspects in more detail. In the Danish case disputable choices are made with respect to the aspects of the functional unit and the electricity scenario. This has major consequences for the results. The issue on recycling is important, because scientifically several approaches are possible which leads to results that can differ up to a factor 4.
These three aspects will be discussed in the next paragraphs.

4.2 Goal and scope definition: Functional unit

In the goal and scope definition phase, as defined by the LCA ISO framework the products, the reasons for carrying out the study and the intended audience are defined. The scope is the detailed technical description of the "product system". Also, the functional unit is defined, which is the base for comparison in an LCA.

The ISO standards require that a functional unit should relate the *function or performance* of the product. Also, the ISO standards require that the compared product systems are in fact comparable. This should be explicitely justified, when a "comparative assertion is made to the public".
Both these requirements are not met in the Danish case. Here the functional unit is *1 kilogram of average packaging material*.

The LCA practitioners of the Danish case recognise that this is not according to LCA practice, but argue that it is in accordance with the premises of the Packaging Tax, which is based on the weight of the packaging materials. They note that the environmental performance of a specific packaging (beverage can or bottle) will appear at the time when the tax is calculated by multiplying the environmental impact per kilogram and the weight of the packaging.

The choice for this functional unit is highly criticised by the packaging industry, by LCA practitioners [12] and by CE.
It is argued that using the weight of the packaging materials as a functional unit is not correct. It disregards the functionality of the packaging, for example as protection during transportation and against product decay. Relevant processes such as the secondary packaging system which are very relevant for transport, filling, washing and others are excluded from the LCA[12].
The function of a packaging is to protect the product during distribution, meaning that a functional unit "distribution of a product (volume or weight)" would be more appropriate, than the chosen kg packaging materials. The consequence would be that LCA's need to be conducted for all different packaging types and products.
The reply of the Danish EPA stating that conducting LCA's for the wide variety of packaging systems and products would be necessary if a proper func-

[12] For refillable packaging these processes can amount to 25% - 30% of the total environmental impact.

tional unit were selected are not considered valid. The complexity cannot not be an excuse to not follow the ISO requirements.

The choice of this functional unit is a direct consequence of the objective the LCA relating it directly to the purposes of the Tax. The objective of the LCA is described as: *To develop a model for establishing environmental profiles for certain types of packaging which can be used in setting packaging taxes for those materials.[…].*
So, already in the purpose of the tax the focus is on packaging materials, and *not on the environmental consequences of the use of the different packaging materials*.

4.3 Energy scenarios

Another important factor determining the LCA results for aluminium concerns the energy scenarios. We briefly explain the backgrounds and then proceed to present the conclusions and recommendations as derived from the case studies.

4.3.1 Theoretical background and ISO standards

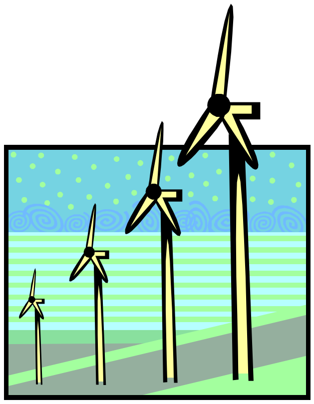
For the production of aluminium a relatively high amount of electrical energy is needed. This electricity is generated in power plants fueled by a mix of fossil fuels as gas, oil or coal, nuclear power, or renewables as wind, water or solar power. Different power plants each fueled with a specific "production mix" contribute to a regional or national grid.
The environmental impact of the "electricity" that is used for the aluminium production depends on the mix of energy sources. A mix with a high share of clean and renewable hydropower will have a lower impact than a mix with a high share of brown coal.

The choices and assumptions concerning the "electricity model" or production mix used in the LCA are a highly significant for the end results.

For the production of aluminium from alumina a large amount of electricity is required. Subsequently, the environmental impact that can be attributed to aluminium is largely caused by the use of electricity. Both the amount and the way the electricity is generated are determining factors. The amount depends on the aluminium production process.

- **Aluminium production process:** The consumption of electricity at aluminium production depends on the smelter[13]. For primary aluminium production the electricity use differs from about 13.5 to 17 kWh/kg aluminium. This difference of 26% has not been subject to discussion in the considered LCA's because it is almost impossible to be sure from which smelter the used aluminium originates. Therefore an average is used. It will not be discussed any further here.
- **Electricity generation process:** The environmental impact of electricity generation depends on the way of generation. The difference between hydropower (4 kg CO_2/MWhe) and brown coal electricity (1,340 kg CO_2/MWhe) is a factor 335! Most of the time the aluminium smelters take their electricity from "the grid", meaning that it is hard to say which kind of electricity is used exactly for the production of aluminium.

[13] It also depends on the input, the recycling of aluminium requires 20 times less energy than the production of primary aluminium. We deal with this aspect in the next chapter, allocation of recycling.

The ISO standards[14] specify the following for the energy data:

- For electricity production: account should be taken of the production mix and the efficiencies of combustion, conversion, transmission and distribution. Whenever possible the *actual* production mix should be used in order to reflect the various types of fuel that are consumed.
- For combustible material: This can be transformed into energy input (in MJ) by multiplying it by the relevant heat of combustion. It should be reported if the higher or lower heating value is used. The same procedure should be applied consistently.

In general, the ISO standards require a sensitivity analysis for parameters that may influence the outcome significantly.

Clearly, ISO does not specify any particular energy-scenario (e.g. the production mix). It only states that assumptions should be clearly stated and justified.

There are different approaches possible when the environmental impact of the electricity consumption is determined. We shortly describe some of the approaches that have been used in LCA practice in general. We refer to a study by Koch-Harnish (EcoFys), where four scenarios are described [22]:

1 Average European grid electricity production
The average environmental impact of electricity production in Europe.
2 National Grid mix approach
The average environmental impact of electricity production of the country the smelter is located in.
3 Contract mix approach
The average environmental impact of electricity production of the electricity supplier of the smelter.
4 Dedicated power mix approach
Aluminium smelters are often build next to a power plant which is dedicated for that plant. The environmental impact is determined by the environmental impact of that plant.

In addition the following two other scenarios's are also used in LCA's:

5 Marginal electricity approach/peak load approach
(Extra) production of aluminium leads to extra electricity demand. The way this (marginal) electricity is generated determines the environmental impact of electricity used.

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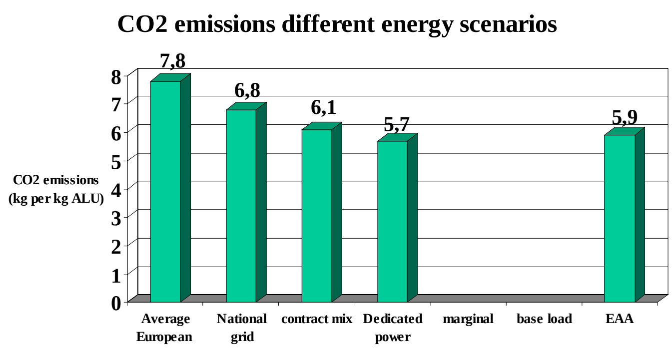
14 ISO 14040 § 5.2.2 and ISO 14041 §6.4 Calculation procedures.

6 Base load approach
Aluminium production is a continuous process and therefore the electricity production units which also work continuously (base load) provide electricity for aluminium production.

The EAA emphasises the importance of using a proper and justifiable electricity-model. For this reason, the EAA has invested in the construction of a a "European model" accounting for the regional electricity import of aluminium from three different regions (Europe, Wester World, Russia). It is presented in the the Environmental Profile Report for the European Aluminium Industry, first published 1996 and actualised in 2000.[21]

Figure 2 CO_2 emissions different energy scenario's



The following data illustrate the range between these different energy scenarios:
Using EAA data results in specific emission of 5.9 kg CO_2-equivalent/kg Alu. The Koch-Harnish study of Ecofys gives a low value of 5.7 kg CO_2-eq for the dedicated power plant approach en a high value of 7.8 kg CO_2-eq for the average European grid mix approach. In this way a realistic estimation is reached of the average CO_2-emission of all aluminium produced in the EU.
It can be expected that in future LCA's practitioners will use the range provided by Koch-Harnish of 5.7 kg CO_2 and 7.8 kg CO_2 as the range for the sensitivity analysis.

4.3.2 Used energy scenario's in the four cases

In the matrix the used energy scenario's for the several processes in the four case studies are listed.

Table 1 Overview of the used energy scenario's in the four cases

Processes	Aluminium packaging		Aluminium building material	
	Danish case	German case	Dutch case	Swiss case
Primary production of Aluminium	Aluminium electricity production; unclear but it seems that a 100% coal scenario is used	EAA data 1996	EAA data 1996	EAA data 1996
Manufacturing of product	Electricity production Denmark 1992; production mix not specified	EAA data 1996	EAA data 1996	EAA data 1996 Partly own production data ALCAN
Assembling	Not relevant	Not relevant	ETH data 1996 EU production mix	Not specified but not very relevant
Recycling	Electricity production EC 1990; production mix not specified	German production mix of 1995	EAA data 1996 European model	EAA data 1996
Sensitivity Analysis	EC marginal electricity scenario for all processes	Production mix for primary Al with technology in Eastern Europe/ US	No analysis	specific data ALCAN
Position Al-industry	**Used data are outdated and not transparant.**	**Agrees with used data**	**Agrees with used data**	**Agrees with used data**

General comment
All cases use the data provided by EAA of 1996 for the aluminium production, with exception of the Danish case. The scenario's used in the sensitivity analysis differs per case. There is no systematic approach visible, although the choice of alternative scenarios is justified in all LCA's.

Danish case
The LCA report does not specify the electricity scenario that was applied. In the sensitivity analysis all scenario's are replaced by the EU marginal electricity scenario, which is condensed coal based, long term marginal technology. This sensitivity analysis showed no effects for the emissions of CO_2, suggesting that the base case electricity scenario used for the results is based on coal. Using such a scenario is questionable and was subject to intense debate in another LCA on beverage packaging in Denmark [9]. For aluminium this choice is highly disadvantageous for the results. Also, the industry points out that disadvantageous outdated data are used.

German case (UBAII)
For the sensitivity analysis a scenario is constructed accounting for the fact that technologies in Eastern Europe and the United States are less advanced environmentally and will generally show higher emissions. So here the technology is varied rather than the production mix. This is not generally common practice. It forms a worse case scenario, where the environmental impacts may end up 40-50% higher (acidification and eutrophication). A best case scenario was not constructed as an alternative.

Dutch case (MRPI)
For the placing of the building product in the building (assembling) it would be more accurate to use the Dutch energy mix instead of the average European mix. However the impact of energy used for assembling is very low compared with the primary production.

Swiss case (facade panel)
No comment.

4.3.3 Conclusions

The electricity scenario can have a major effect on the emissions of CO_2. This is clearly demonstarted by the sensitivity analyses. However, in most of the considered cases the use of energy scenarios is not subject of discussion and perceived as problematic by the stakeholders. There seems to be concensus amongst LCA practitioners regarding the use of the scenario provided by EAA.
The choice for alternative scenarios that are used for the the sensitivity analyses differ per case. More consistency in used method is desirable.

4.3.4 Recommendations

The following recommendation can be derived from the case study analysis:

- The used scenario and production mix of energy must always be clearly specified (as is required by the ISO standards.
- Use the most recent EAA database for the primary Aluminium production.
- In the LCI data provided by the EAA it could be considered to mention ranges of the emissions for the sensitivity analysis. It can be expected that LCA practitioners who will choose a certain range based on the Koch Harnish results. This can have a major effect on the results of the LCA.

4.4 Credits for recycling

Another important factor determining the LCA results for aluminium concerns recycling. We briefly explain the backgrounds and then proceed to present the conclusions and recommendations as derived from the case studies.

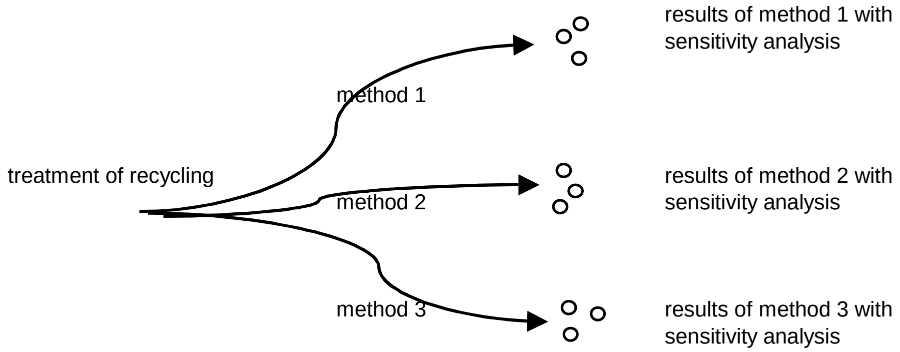
4.4.1 Theoretical background and ISO standards

Due to its inherent properties aluminium is a highly suitable material for recycling. The aluminium industry points out that for most applications aluminium is not *consumed* but rather *used*. The value of aluminium is high after recycling and the recycling rates of aluminium products are also high. In effect, this means that less energy consuming virgin (primary or raw) material needs to be produced. This results in a substantial reduction of the environmental impact that can be contributed to the use of aluminium.

In practice, there is not much discussion about the recycling percentage of aluminium. The discussion is about the way recycling is credited or allocated. When the aluminium is recycled and then used in another product, the environmental benefits can be attributed to both the product system of the LCA and to the other product system. LCA practitioners have developed a number of methods to deal with the crediting of recycling, each leading to different outcomes of the LCA. For aluminium products, these differences can amount up to a factor 4.
A particular choice of method is generally justified by underlying assumptions concerning the recycling markets (demand, availability) or the conceived effects of changes in the product system on these markets.

The ISO standards provide a set of principles and procedures that specify how to account for reuse and recycling. However, these do not provide a definite blueprint. Providing the assumptions are specified, documented and justified[15] a variety of methods remain possible, each being equally valid[16]. Each method has its own reasoning and is scientifically valid. Yet, each can lead to a totally other result. In the graph this is visualised.

Figure 3 Diverging outcomes depending on the choice of method



It is important to realise that “the truth” is **not** somewhere in between the results of the three methods. Each method has a specific outcome with a range as result of variations in recycling rates or technologies (the sensitivity analysis). Crediting for recycling can lead to totally different results and each result has its own truth, politicians and policymakers must be aware of this.

Aware of the importance of this issue and of the impact on the LCA outcome, the EAA prepared a document to aid LCA practitioners with specific recommendations on how to deal with recycling of aluminium in LCA’s (the key feature document “How to treat aluminium in LCAs'” [20]).

The outlines of the ISO procedures regarding recycling crediting are presented here.

- When the recycled material is reused in the same product system, this is called **closed loop recycling**. No allocation is needed in this case, because all recycled aluminium substitutes a similar amount of primary aluminium. The Key feature document refers to this closed loop allocation as the substitution method. This situation can be created by expanding the product system to include the co-products. This method is prefered by the ISO standards.
- In a situation of **open loop recycling with no changes of the material properties** ISO states that the system may be considered as a closed loop system. Allocation can also be avoided. This is understandable considering that the recycled aluminium once returned to the market is indistinguishable from primary aluminium. The actual history of the material has become irrelevant.
- In a situation of **open loop recycling with changes of the material properties** a more complicated approach is needed. Several methods are applicable. The Key feature document favours the *value corrected substitution method.* This method assumes a proportionality of the

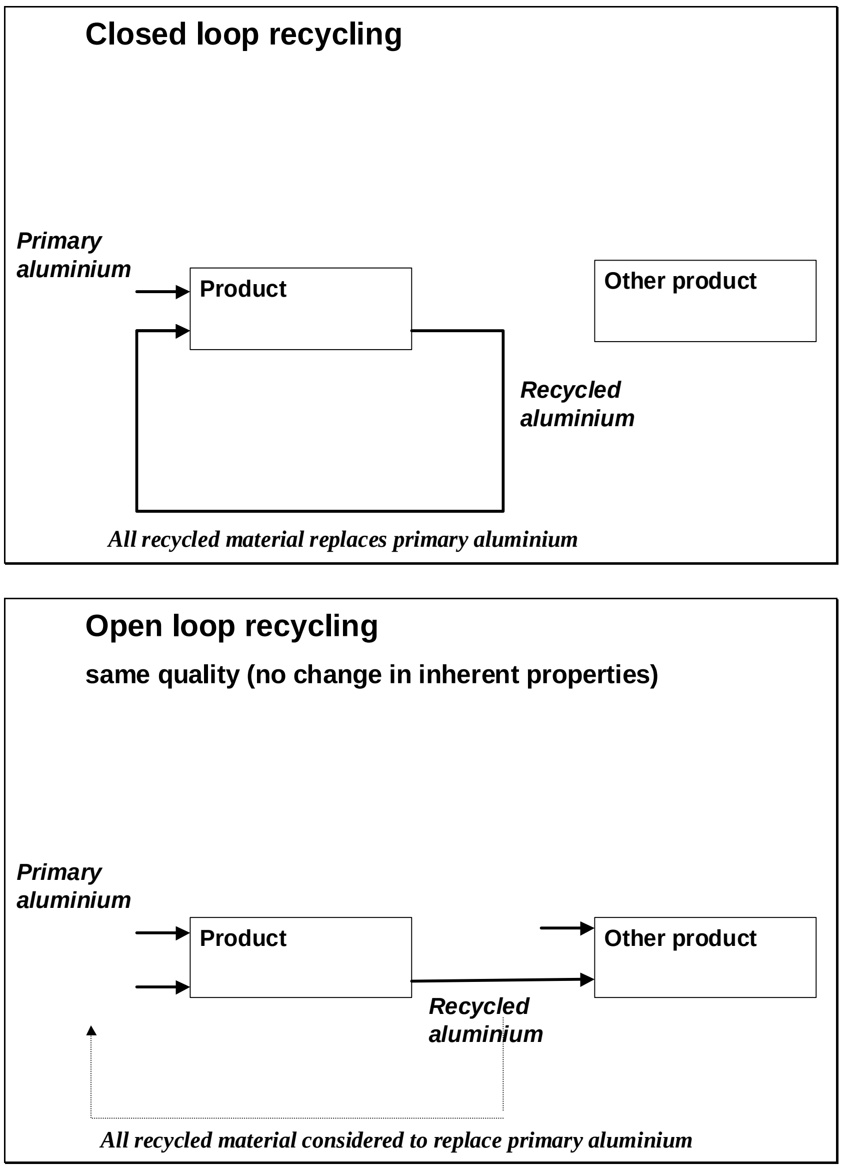
[15] ISO 14040 § 5.1.2 and § 5.2.2.

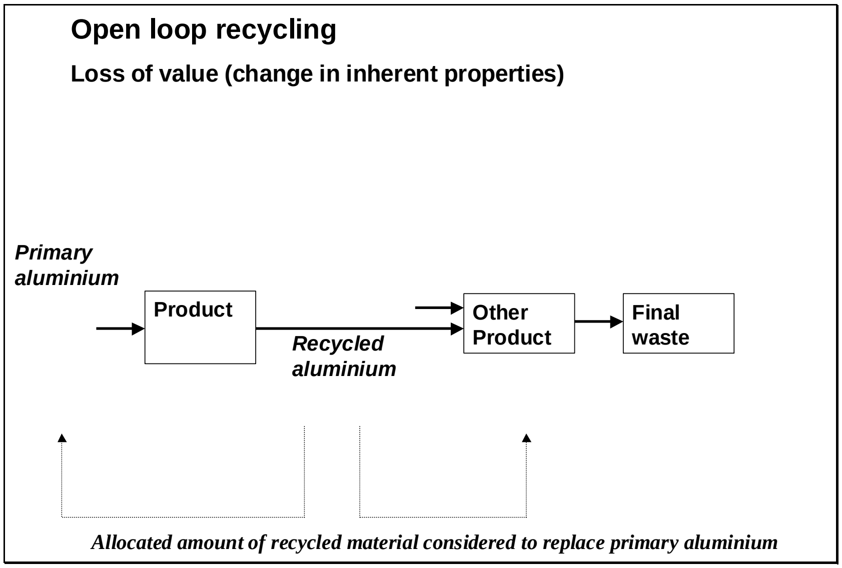
[16] ISO 14041 §6.5 Allocation of flows and releases.

environmental burdens caused by primary material production and final disposal and the (economic) value of the recycled material. The environmental burdens are partitioned between both productsystems. Other methods are also possible, such as the *recycled materials content approach*, where credits are only given on the input side, i.e the content of recycled aluminium.

In general, the ISO standards require a sensitivity analysis for parameters that may influence the outcome significantly. Clearly, recycling is an important parameter for aluminium.

Figure 4 Different recycling situations





4.4.2 Used crediting for recycling scenario's in the four cases

The matrix presents an overview of the methods used for crediting of recycling in the four casestudies.

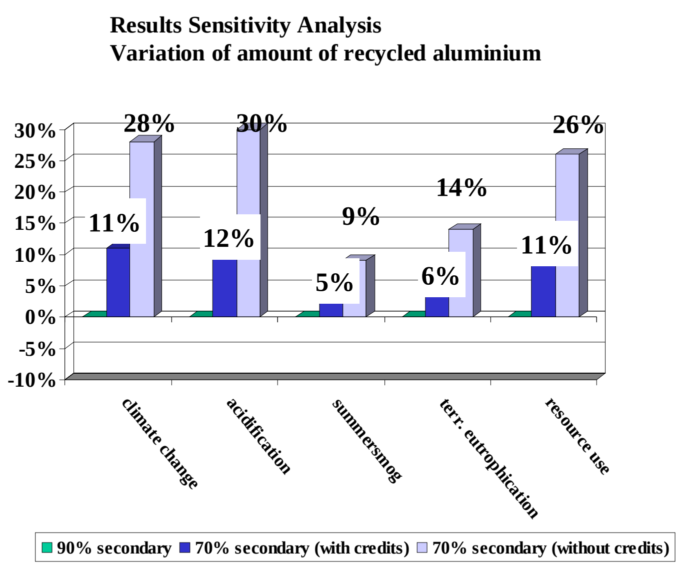
Table 2 Overview of the used scenarios for treatment of recycling in the four cases

	Aluminium packaging		Aluminium building material	
	Danish case	German case	Dutch case	Swiss case
Used method(s)	Substit. method. Closed loop approach	Substit. method Partially closed loop and partially open loop approach	Substit. method Closed loop approach	Substit. method Closed loop and value corrected open loop
Remark on used method	All recycled aluminium replaces primary; loss in recycling 5%	Closed loop system has a maximum recycling%; deficit or excess recycled Alu comes from/goes to open loop system in which it replaces 57% primary and 43% sec. Alu	All recycled aluminium replaces primary; loss in recycling 5%	All recycled aluminium replaces primary; loss in recycling 1%-10%
Used recycling %	10% recycling; 90% incineration (in Tax Proposal)	75% of Alu cans is recycled In closed loop system 90% for can bodies. For can lids 0% recycled aluminium.	94% recycling, loss 5% results in 89% secondary Al that replaces primary Al	100% recycling, loss 1%-10%
Other methods used in sensitivity analysis	None	Open loop without substitution Variation of the input of recycled material from 90% to 70%. Variation of percentage of primary/ secondary aluminium to 72,4%.	"DHV estafette" and value base substitution method, recycled content approach	Both used methods result in the range of 1%-10% loss
Position Al-industry	**Agrees with the used method. Not with fixed recycling %.**	**Used method is complicated and not fully transparent. However it is acceptable.**	**Agrees with used method**	**LCA for internal use Alcan**

Danish case
In the Danish case the discussions focus on the choice of the recycling percentage. Here, the environmental profile of aluminium and consequently the tax rate is based on a recycling percentage of 10%. This reflects the present situation in Denmark where most household waste is incinerated rather than recycled. An alternative scenario using 90% recycling was calculated in the LCA study. However, this was not used in the Tax Proposal.
The industry criticises this, arguing that the potential positive effects of recycling are not taken into account. They point out that the Danish government (EPA) never responded to the initiatives taken up by industry to improve the recycling rates. If this had been the case, the recycling rates would be higher resulting in a substantially lower Tax Index (i.e. with Swiss or German rates: 6-12 instead of 18). They also argue that the tax system provides no incentive to improve the recycling rates.

German case
The crediting method used in the UBA II study is complicated and lacks transparency.
A sensitivity analysis was carried varying the recycling rates for the beverage cans from 90% to 70%. Also, all results are presented both 'with' and 'without' credits. The following figure illustrates the effect of the sensitivity analysis. Clearly, the influence of both the recycling percentage and the method is significant (5-30%).

Figure 5 Results Sensitivity Analysis Variation of amount of recycled aluminium

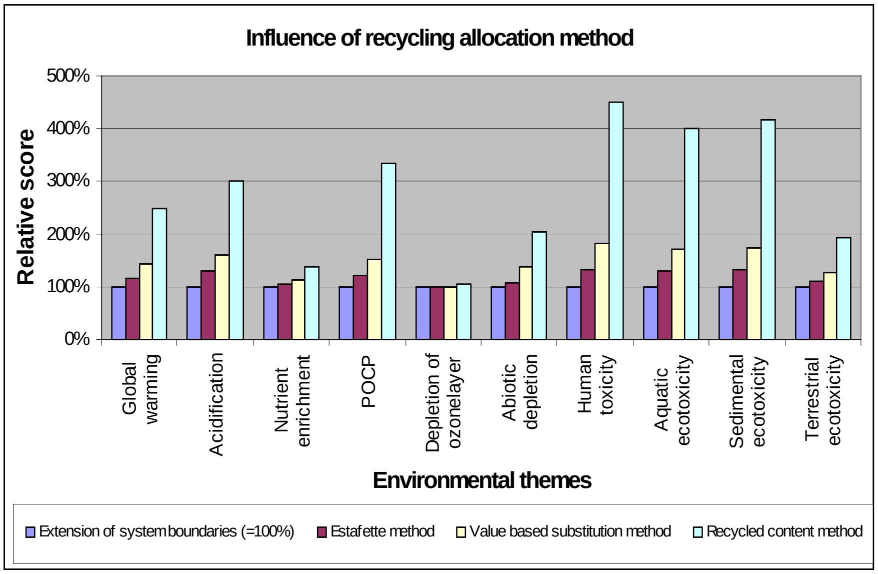


UBAII aluminium cans 33cl

Dutch case
The standard allocation method for MRPI is based on the "recycled content" approach. Here the percentage of secondary materials is based on the input of secondary materials. However, it is also agreed that for industries that (have) invested actively in setting up a recycling system are allowed to get credits for this as well. In this case allocation based on output recycling (substitution) can be used, as well.
The method for treatment of recycling was discussed and agreed for the whole MRPI system before the LCA's of products were carried out. This has

the effect that no discussion about recycling takes place in the separate LCA's.
The figure illustrates the influence of the choice of allocation method. This can amount to a factor 4!

Figure 6 Influence of the choice of allocation method



Comment Swiss case
No comment.

4.4.3 Conclusions

With respect to recycling two aspects can be distinguished that have a significant influence on the LCA outcome:
1 The recycling rates.
2 The choice of allocation method.

Within the ISO framework several allocation methods are scientifically valid, each leading to significantly different outcomes.
In the case studies crediting of recycling is carried out using the substitution method with closed or/and open loop. For the sensitivity analyses different methods are used. The used substitution method with open loop and closed loop in the cases do not result in large difference in the result. The used method in the sensitivity analyses in the German case leads to a different result.

The recycling percentage that is used in the LCAs depends on the country and the kind of product. Also the waste processing method with possible energy production from aluminium differs per country.

4.4.4 Recommendations

The following recommendation can be derived from the case study analysis:

- Due to the multifunctionality of the aluminium it is preferable to use the value corrected substitution method with closed loop or open loop recycling for aluminium. According ISO 14041 for Aluminium an open loop system can also be considered as closed loop when it is corrected for losses and eventually the loss of value.
- In the sensitivity analysis other methods should be used to assess the influence on the method on the LCA results. The industry can advise the LCA practioners on this issue.
- Politicians and policy makers must be made clear that the result of each method for allocating recycling is as valid or “true” as another method.

5 Impact assessment and weighting

5.1 Introduction

Weighing of impact categories is a very important issue, especially when it is used for legislation based on LCA's. Weighting refers to the process where the results of different environmental impacts are added up to one or several indicators, using factors that reflect political preferences.
In the German case study, there was agreement about the results of the impact assessment of the LCA between UBA and the Industry. However, the results were then ranked/weighed by UBA, which resulted in a very disadvantageous outcome for the Industry. It seems that with a weighing system you can come to almost any favoured result.
At present, there is no scientific consensus about any weighting or ranking method. LCA practitioners have developed a variety of techniques and methods. Weighting is not allowed by the ISO standards when an LCA entails a comparative assertion and is also disclosed to the public. For in-company use, of course, weighting can be applied.

Here we will discuss the issue of weighting in more detail and present the finding of the four case studies.

5.2 Theoretical background and ISO standards

In the impact assessment phase of an LCA all emissions are categorised according to their environmental effect into a number of distinct impact categories i.e global warming, acidification, land use, resource depletion etc. As many as fifteen categories can be identified. In practice, LCA practitioners select the most relevant of these impacts in the goal and scope definition phase of the LCA. The ISO standards require that this selection is justified properly.

LCA practitioners have also developed a variety of techniques and methods to support the interpretation of the impact assessment results. The aim is to facilitate the decision making process by reducing the amount of indicators.
These entail normalisation, ranking or grouping and weighting.

- With *normalisation* the results of each impact category are related to national or international figures.
- With *ranking* a prioritisation is carried out between impact categories. For example the results on climate change are given higher priority than land-use.
- With *weighting* numerical values are used to prioritise. Either by using these as scale factors or by aggregating the results using these values to obtain one or more end indicators.

The ISO standards specify that these procedures are optional additional procedures of the impact assessment.

At present there is no scientific consensus on how weighting should be done. All weighting methods are inherently subjective, reflecting political value-choices. For this reason, the ISO standard explicitely do **not** allow a weighting procedure for an LCA making comparative assertions disclosed to the public. The standards state that this procedures are inherently *based on (political) value choices and are not based on natural science*. Ranking methods may be used as long as the ranking method is transparent and the results of the seperate impact categories remain visible.

5.3 Used weighting in the four cases

In the matrix the used weighting methods in the four cases are presented.

Table 3 Overview of the used weighting methods in the four cases

	Aluminium packaging		Aluminium building material	
	Danish case	German case	Dutch case	Swiss case
Impact categories	1 Global warming 2 Acidification 3 Nutrient enrichm. 4 Photoch. Ozone 5 Depletion 6 Wastes	1 Global warming 2 Acidification 3 Nutrient enrichm. 4 Photoch. Ozone (5 Human toxicity) (6 Ecotoxicity) 7 Depletion 8 Land use (2 categ.)	1 Global warming 2 Acidification 3 Depletion ozonlayer 4 Nutrient enrichm. 5 Photoch. Ozone 6 Human toxicity 7 Ecotoxicity 8 Depletion 9 Waste (2 categories)	1 Global warming 2 Acidification 3 Nutrient enrichm. 4 Photoch. Ozone 5 Human toxicity 6 Ecotoxicity 7 Depletion 8 Water consumption 9 Radioactivity 10 Waste (6 categories)
Aggregated Categories	a Emissions: 1, 2, 3 and 4 b Depletion c Wastes	None	a Energy use b Emissions: 1, 2, 3, 4, 5, 6 and 7 c Depletion d Hazardous waste e Non-haz. waste	
Weighting/ ranking method	Combination of normalisation and distance to target	Ranking within 3 criteria: irreversibility of effects, distance to target, normalisation	Normalised emissions are summarised	Complicated method with market value of the product
Position Al-industry	Because it is a comparative disclosure to the public weighting is not allowed	Does not agree with the ranking method, especially the ranking with normalisation can be seen as weighting	Agrees with weighting method in the existing MRPI system, possibly the method will be left	The method is designed by Alcan
Conformity with ISO	Not	Doubtful	Not	Yes, because the study is not disclosed to the public, it is for internal use.

Danish case
With respect to the selection of impact categories:
- The Danish LCA only considers the use of the resources pit coal, oil and natural gas. The resources use for aluminium (bauxite), iron ore, maganese and lignite are not considered *to simplify the number of assessment parameters, in compliance with the wishes of the Environmental Agency [7].*
- The impact categories human toxicity and eco-toxicity are not included due to lack of data. This is criticised by the industry, because it may lead to sub-optimalisation.

The impact categories are aggregated by use of weighting into three categories in the LCA:

a The weighted emissions: impact of global warming, acidification, nutrient enrichment and photochemical ozone formation (here: emissions).

b Weighted Resource depletion.
c Weighted wastes.

The weighting method based on political targets is not transparent.

The Tax Proposal takes this weighting one step further by discarding the last two categories and basing the Tax rate Index on the weighted emissions only. This procedure is explicitly presented by the EPA as a political value choice.
No sensitivity analysis with other weighting factors is carried out.

German case
The interpretation of the impact assessment results is explicitely carried out by the German government (UBA) and not by the LCA practitioners. The LCA report consists of two distinct parts: 1. LCA inventory and impact assessment (LCA practitioners) and 2. Ranking and Interpretation (by UBA). Much effort is invested in the development of a ranking system. This is worked out in a separate document "Bewertung in kobilanzen (1999)". It is explicitely referred to as ranking in the UBAII study and **not** weighting (which is not allowed by the ISO standards).
In short: The impact categories are valued on basis of three criteria: irreversibility of effects, distance-to-target and normalisation. Combinations of the three ranking criteria, leads to the final ranking on ecological priority. For the aluminium cans, the category global warming is considered most important, followed by acidification, terrestic nutrient enrichment, Summer smog and resource use. Land use and aquatic nutrient enrichment is given relatively low priority.

The ranking system is highly criticised by the German Industry. It is argued that the distinction between ranking and weighting is not clear. Also, the applied ranking methodology is not transparant. Why three ranking criteria and not two or four? Also, using different ranking methods different conclusions can be equally justified. Aluminium beverage cans can also be considered as equivalent to the returnable glass bottles, instead of being classified as being more damaging to the environment. It allows the suggestion that the ranking method was specifically developed to reach a favourable outcome.

We (CE) agree with this criticism[17].

Dutch case
All emissions are normalised and that simply added to one indicator: emissions. This used method clearly is weighting. This is in accordance with the ISO specifications. However, it is agreed between the industry and the LCA practitioners. It is still being discussed whether the weighting method will be used in the next step to the regulation concerning the material related environmental performance system on buildings (MMG).

Swiss case
The Swiss LCA is a study made for in-company purposes. Weighting was carried out (which is of course allowed).

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17 For example: The ranking on basis of the third criterion is not transparent and also questionable. For example, it is not clear why the lowest value of refillable glass bottles or aluminium cans is chosen for the ranking value and not the highest value. Low normalised values are given a low ranking. This is a choice. The implication of this choice is that when an industry has put a lot of effort in lowering the emission on an impact category, the bonus is a low ranking.

In short: The calculated contributions to the considered impact categories are weighted by multiplication of each contribution with three factors in order to be able to make a more explicit distinction between different product systems on the basis of environmental profiles.

- The first factor represents the subjective assessment of the significance of a given impact category according to the opinion of the authors of the LCA. Applied values for this factor are:
  1 = minor importance;
  2 = medium importance;
  3 = important;
  4 = very important.
  Application of this factor could be regarded as a form of distance to target weighting.
- The second factor is a measure for the accuracy of the calculated contributions. Results with a presumably small uncertainty are multiplied with a factor 3, for less reliable results and results with a very large uncertainty the normalised contributions are multiplied with a factor of respectively 2 and 1.
- The third factor is the average of the normalised contributions of the considered ten product systems to an impact category.

Finally, the resulting factors are remodelled into a scaling factor per impact category by dividing them by the average not-normalised contribution of the ten considered product systems to the considered impact category. For impact categories for which no information on total European contribution is available an average normalised contribution of the ten considered product systems of 1 is assumed.

The applied methodology for weighting is quit unique, not applied in any other LCA as far as we know. No argumentation is given why this methodology is given, why for example the accuracy of the calculated contributions plays such an important role and what the benefit is of multiplication in first instance with the average normalised contribution and dividing in second instance by the average un-normalised contribution.

5.4 Conclusions

There is no consistency concerning the selection of impact categories between the considered LCA’s. Only global warming, acidification, nutrient enrichment and photochemical ozone formation are analysed in all four LCA's. In all LCA's resource depletion is considered, but the depleted sources differ per LCA. Three out of the four LCA’s distinguishe a category “Waste”. This is not an impact category according to the requirements of the ISO standards. The end-effects of waste are generally accounted for by the other categories such as climate change, landuse etc.

All LCA's use different methods for aggregation or weighting. In all the weighting methods normalisation plays an important role. It must be stated that summarising or ranking with normalised values can be considered a form of weighting. Often it is presented as a scientific method, but that is not correct. Normalisation can be done with emission data of the country, in which the LCA is made, data of Europe or global data. So the normalisation depends on the reference and the choice of the reference is a political one.

The results of a comparative LCA are difficult to interpret due to the fact that the results on the separate impact categories cannot be mutually compared.

It is understandable that a clear result is wanted. Especially politicians prefer a clear result on the environmental aspect, seeing that they also have to take into account other aspects like social and economical. Weighting methods are designed to get such a clear environmental result. It is the task of researchers to advise politicians on this topic. At present almost every LCA practitioner designs his own weighting method There is no scientific consensus. Consequently, the results of the weighting are not comparable. In comparative LCA's disclosed to the public weighting should be based on a political decision.

5.5 Recommendations

The following recommendation can be derived from the case study analysis:

- As long as consensus is lacking concerning the selection of the impact categories, one cannot use an LCA for comparing several products with each other in a legislative framework.
- As long as consensus is lacking about the weighting method one cannot use an LCA for comparing several products with each other in a legislative framework.
- All weighting methods are inherently subjective, reflecting political value-choices. The weighting process is at all times an explicit political process.

6 The LCA process

6.1 Introduction

A LCA is more than a just 'scientific' study. Even when all ISO standard requirements are met the outcome can still remain disputable. The authority and acceptance of the outcome is as much determined by the LCA process, which entails the time period leading to the assignment, the execution of the LCA, the presentation of the results and also the implementation of the results.

How was this process managed and structured in the situation of the four cases and which stakeholders were consulted. How do the relevant parties assess the quality of this process? Here we discuss this issue in more detail.

6.2 Theoretical backgrounds and ISO

In the past few years the LCA practitioners have given increasing attention to the management of the LCA process. New methodologies are presently being developed to structure the management of the LCA process. It is not possible here to give an extensive overview of the insights that have been gained on the subject. However, we shortly refer to the "Operational guide to the ISO standards", that was recently published by the Centre of Environmental Science of Leiden of the Netherlands (CML) [18]. In this Guide an interesting framework is presented. In effect it distinguishes two dominant factors that influence the LCA process: the number of parties with diverging interests and the relative potential impact of the results. In this way four types of process contexts are distinguished:

I Strong potential impact/ few diverging interests (shared views)
II Low potential impact/ many diverging interests
III Strong potential impact/ many diverging interests
IV Low potential impact/ few diverging interests (shared views)

Each process context requires a different management approach concerning the assignment, critical review, process-planning and stakeholder participation. The LCA Guide gives guidelines and procedures for each of these situations. Obviously situation III will require the most care regarding the management of the process in terms of stakeholder participation or quality of the critical review.

The ISO standards specify that a critical review is mandatory in the case of a comparative assertion made to the public. This can be carried out by internal or external experts or by a stakeholder panel.

At present the ISO standards do not provide any guidelines or recommendations concerning the management during the conduction period of the LCA. Possibly, the here mentioned recent scientific developments will in the future lead to standardisation in ISO standards.

6.3 Cases

Here we summarise the LCA process of the four case studies.

6.3.1 Danish case: Tax Law

A few hearing rounds have taken place where concerned parties were given the opportunity to comment on the Tax proposal. It is not clear whether there were any hearing rounds during the time the actual LCA was carried out.

One of the key points of criticism of the Danish packaging industry is that there has been no proper consultation of the industry. The hearing rounds took place at a time when the tax was more or less definite. Therefore, the actual possibilities for influencing the results were very limited. After the tax law came into force in November 2000 the industry invited the Environmental Protection Agency (EPA) for a discussion. These resulted in only a few amendments to the original proposal (i.e the influence of transport was included leading to a slight lower of the Index for aluminium).

No critical review was carried out. The industry asked an independent LCA practitioner to evaluate the LCA and the Tax Proposal [12]. This evaluation was highly critical.

Using the process framework provided by CML, the context of the Danish LCA can be described as a situation with a strong potential impact and with many diverging views. The objective was to determine environmental profiles that were to be used to establish the tax rates of the Packaging Tax.

6.3.2 German case: UBAII

In this case much attention was paid to the management of the LCA process. Prior to the start of the UBA II study, representatives of the German industry (Bundesverband der Deutschen Industrie) and the Umwelt Bundes Amt agreed on a set of ‘Procedurals Rules for Perfoming LCA’s’ (Code of Conduct). These mainly ensure a proper participation of concerned parties during the conducting process of the LCA. In adherence to these rules a project advisory committee was set up to support the UBAII process, containing representatives of all the concerned parties. The LCA was carried out in adherence to ISO. A critical review panel evaluated the LCA.

Despite the shared aim of all parties to adhere to the Code of Conduct, the industry takes the view that the intended spirit behind the Code of Conduct was not applied appropriately, mainly concerning transparency, fair and open discussions. This criticism accounts especially for the interpretation phase. The development of the ranking methodology, the interpretation and the final presentation of results were carried out by the Umwelt Bundes Amt, without consultation of the involved parties. The quality of the consultation during the LCA phases of the inventory analysis and the impact assessment is considered acceptable.

The interests of the industry and the government with respect to the LCA were more or less shared at the onset of the study. The purpose was to obtain more insight in the environmental impacts of the packagings and stimulate innovations. The interests diverge at the point where the German government interpretation results in explicit comparative assertions favouring one packaging to the other.

Also, the interests diverge when the government considers legislation on basis of a LCA. Till this moment no such measures have been based on the UBA II results. The general view of the German industry on the use of LCA's in policy making is expressed in the BDI Position Paper. The industry is generally opposed to use of LCA's as a justification for legislation discriminating between products.

The German UBA II case can also be described as a situation where a strong potential impact could be expected, seeing that the political discussions concerning packagings have a long history in Germany (GrQne Punkt, DSD).

6.3.3 Dutch case: building MRPI

The general framework for the LCA of building products in the system of MRPI's is discussed and decided by the industry with support of LCA specialists. Also the weighting step is part of the agreement within the involved industry. Within the MRPI system a certified LCA bureau carries out an LCA. Also a certified bureau performs a critical review. Governmental parties and NGO's are not involved in the MRPI.

6.3.4 Swiss case: company internal

The LCA for facade sheets is made for company internal purposes and therefore results from an internal process. The political context is therefore limited. Discussions with the Swiss legislators have taken place outside the framework of this specific LCA study. This is described in Chapter 2.2.4.

6.4 Overview

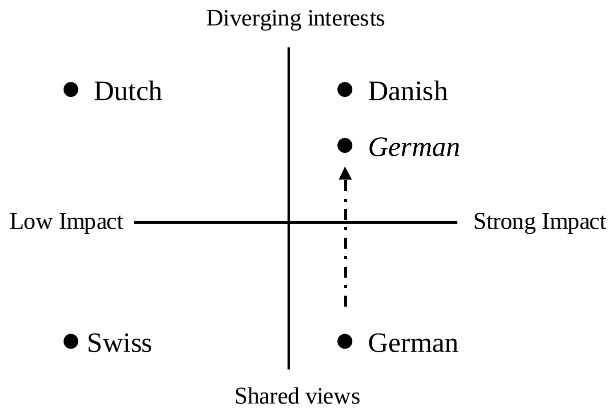
In the matrix the process management aspects are listed.

Table 4 Overview of the process management in the four cases

	Aluminium packaging		Aluminium building material	
	Danish case	German case	Dutch case	Swiss case
LCA process	No involvement of steering/advisory committee	Advisory committee was involved	No involvement of NGO's	No involvement of government & NGO's
Weighting process	A few hearing rounds	The industry was not consulted	No involvement of NGO's	No involvement of government & NGO's
Critical review	No critical review. Only an evaluation afterwards on request of the Industry	Critical review panel	Review by another specialised and certified bureau	The methodology is reviewed, not the LCA itself
Position Al-industry	Disagrees with the whole process	Disagrees with the ranking process and interpretation	Supports the system of MRPI	For internal use
Conformity with ISO	Not	Not	No, but nobody is claiming that it is.	Not relevant because it is for internal use and for customers
Key problem in the process	No involvement of industry nor critical review	No involvement of the industry at the weighting process	None	None

We tried to position the cases on the scales provided by the LCA Guide framework. Interesting is the German case. Here the initial purpose (innovation) and the conclusions (discrimination) are the breaking point for the interests of the industry and the government.

Figure 7 Position of the cases in political context



6.5 Conclusions

Both the Danish and German case describe a situation or process context with a strong potential impact and diverging interests. Clearly this requires much care in the way the LCA process is managed. This is illustrated best by the Danish case. Here the whole process was poorly managed. There was little to no consultation of the concerned parties and no critical review was carried out. The result is that the Tax is now subject of a formal complaint at the European Union.

In the German situation more attention was given to the process. Both the government and the packaging industry (represented by the BDI) mutually agreed on a code of conduct, with emphasis on participation of all concerned parties. However, at the most crucial phase of the LCA, the interpretation and conclusion these parties were not consulted. The result is that the conclusions are not accepted. A critical review was carried out.

The Dutch building case seems to be managed in a proper manner. All parties from the building industry are consulted. The potential impact is a little less strong than in the other cases. There is some risk that the MRPI system will be criticised by the NGO's, because these were not consulted.

It must be stated that despite full involvement of all relevant parties in the process there is no guarantee for a result that is supported by all these parties.

6.6 Recommendations

The following recommendation can be derived from the case study analysis:

– In every phase of the LCA process - from the start of an LCA to the end-especially when ranking or weighting is discussed, the involvement of the stakeholders including representatives of the affected industries is strongly advised. For example by installing an advisory or a steering committee.

- A critical review is an obligatory element of an LCA that makes a comparative assertion disclosed to the public. The necessity of this is illustrated best by the Danish case.
- LCA practitioners are developing methods for the management of the LCA process. Possibly these will result in ISO standardisation. The industry can support the development of methodology and support standardisation.
- Industry can support the development of specific Codes of Conduct as was done in Germany.

7 Conclusions and recommendations

7.1 Introduction

The use of LCA's to support policy making and legislation is expected to increase. Despite the fact that the LCA methodology is not designed for legislative purposes, it can be considered as inevitable that LCA's will be used. The four case studies clearly demonstrate that LCAs are presently being used for legislative purposes. LCAs are not designed for legislation, because different scientific approaches of some LCA aspects are possible, which can lead to totally different outcomes.
Taking this as a starting point - legislation based on LCA's is inevitable - it is advisable for the aluminium industry to participate actively, both in the process of standardisation of LCA's and in the process of a comparative LCA that is relevant to the aluminium industry.

In the next paragraphs the conclusions and recommendations will be formulated regarding the most relevant aspects of LCA's. The analysis of the case studies lead to identification of the following key-aspects that require special care when conducting an LCA:

1. Involvement of the industry in the LCA proces.
2. The inventory aspects functional unit, energy scenario and crediting for recycling.
3. Weighting.

These aspects will be discussed here.

7.2 Involvement of the industry in the LCA process

Quoting a director of Coca Cola Enterprise: *For the company it is crucial to hold control on all the aspects that can influence the market of the product. The costs of this control are less important than loosing control. Loosing control can mean that you loose your market.*
In the past few years it became clear that this philosophy is relevant for the aluminium industry with respect to legislation using LCA's.

Involvement of the industry during the whole process of the LCA proves to be very important. The moment a discussion is started about a product or group of products in which the environmental aspects can play a role, the industry should want to play an active role. The Danish case learns that involvement before the LCA is started is crucial. The definition of the goal and scope of the LCA and the functional unit as a result of this definition caused most of the problems the aluminium industry has with the results of the LCA. The German case learns the relevancy of being alert on the policy discussions about packaging. *Murphy's law: If something can go wrong it will go wrong.* Rephrase: if (politicians think) an LCA can be used for legislation it will be used.
Especially when a discussion has a high political profile, diverging opinions and a high risk, it is crucial that the aluminium industry is involved from the very beginning, before an actual LCA is started. The involvement should continue during the whole process of performing the LCA and the interpretation of the results and the use of the results.

The Dutch and Swiss case learn that it proves to be effective to develop a general framework for the LCA's for a group of products. Within this framework agreements can be made about important aspects such as the energy scenario, recycling, functional unit, the database to be used, etc. This avoids discussions when the LCA's are conducted and ensures comparability of the outcomes. In the Danish case and the German case there was no such framework. In the Dutch case the framework resulted from discussions with LCA specialists and Industry. In the Swiss case the industry was successful in changing the framework with respect to recycling. The aluminium industry should support such developments of framework methodologies for product groups and support standardisation.

If politicians want a (tax) law, they will make one. Realising this the industry can try to influence to which parameters the tax will depend on. In the Danish case the tax was based on the environmental profile that resulted from the LCA, multiplied by the weight of the packaging material. As the environmental profile is fixed, this tax only stimulates weight reduction. Propositions for other incentives in the system like recycling percentage could have given more possibilities for the industry to hold the initiative in influencing the tax law.

Overall conclusion on this topic: be alert and proactive.

7.3 Inventory aspects

The way an LCA is performed determines the result of an LCA. Choices and assumptions made regarding a number of key aspects can be decisive for the outcome. The Aluminium industry must make clear to politicians this can have a major effect and that because of it, it is crucial to follow the ISO standards. After discussion of this analysis document CE will make a document the Industry can use for the discussion with the politicians and policy makers about these aspects.

The first aspect is *the functional unit*. This must be chosen properly and in accordance with the standards. Actually the functional unit of a packaging should also hold aspects as protection to decay of the packed product and offering the desired quantity. The functional unit of building products should also hold aspects as energy consumption during the use phase of the building. These broader functional units have more possibilities for the industry to improve the environmental profile. It could be profitable for the industry to try to broaden the functional unit with these aspects.

The *energy scenario* for the production of aluminium can have a major effect on the result. It must be made clear what realistic scenarios are.

Crediting of recycling can have a major effect on the result too. It must be made clear that there are several methods that are scientifically correct but can lead to a totally different result of the LCA. Each result is correct from a scientifically perspective. It's not just a range as result of a sensitivity analysis, from which you can pick the average.
A critical review is obligatory, also when the LCA practitioner is very experienced. The Danish case learns that failures in figures, functional unit, energy scenario and sensitivity analyses are easily made.

Two recommendations can be formulated which can be considered to put in the EEA Key Features document [20]or in the EAA Environmental Profile report [21].

- The first is to present a range of emission profiles in the environmental profile report, which LCA practitioners can use for the sensitivity analysis. In the Key Feature document this range can be advised. It is better to present a range, otherwise LCA practitioners will construct a range themselves.
- The second is to advise which crediting methods should be used in the sensitivity analysis.

7.4 Weighting

Although weighting in comparative LCA's disclosed to the public is not allowed in ISO politicians will do it or ask the LCA bureau to do so. Politicians prefer to have a limited number of end indicator for the assessment of the environmental effects. Otherwise it is almost impossible for them to make decisions when social, economical and environmental aspects have to be taken in account. Realising that weighting is inevitable it is advisable for the industry to be pro-active in developing a weighting method (or a set of weighting methods) that is supported and acceptable by politicians and scientists.

It is advisable to co-operate on this topic with other industrial sectors like the steel industry and the plastic industry.

7.5 Overview of the recommendations

In the former chapters recommendations are formulated based on the conclusions. In this paragraph these recommendations are assigned to the target group to which the recommendation is directed. Three target groups can be distinguished.

1 The Aluminium Industry.
2 The policymakers and politicians.
3 The LCA practitioners.

The recommendations for the Aluminium Industry are internal. The recommendations for the last two target groups are important for external communication, each requiring a different communication style. The communication to policymakers and politicians are more focussed on the LCA process and to the practitioners more on specific LCA details. Here we mention the recommendations for each target group.

Recommendation for the Aluminium Industry itself

- The Aluminium Industry should initiate a monitoring system to identify possible LCA studies commissioned by politicians/policymakers and linked to possible legislation.
- Present a range for different energy and allocation scenarios in the environmental profile report.
- *Murphy's law: If something can go wrong it will go wrong.* Rephrase: if (politicians think) an LCA can be used for legislation it will be used.
- Be aware that weighting or similar simplifications may be done in the decision-making process.

Recommendations for external communication with politicians and policymakers

- Any commissioned LCA study should be done according to the EN ISO 14040-series standards.
- A critical review panel should be involved at the very early stage of the LCA study and the Aluminium industry should be invited to participate.
- Weighting is not allowed in comparative LCA's disclosed to the public by the EN 14042 standard. An LCA should end with a certain amount of indicators but not with one figure.
- The functional unit should be properly chosen.
- The proper method should be used to take into account the Aluminium recycling abilities.
- Consensus on all key aspects should be reached before the LCA study starts.

Recommendations for external communication with LCA practitioners

- Weighting is not allowed in comparative LCA's disclosed to the public by the EN 14042 standard. An LCA should end with a certain amount of indicators but not with one figure.
- The functional unit must be properly chosen.
- The EAA energy model and the generic data as collected by EAA should be used.
- Aluminium recycling should be considered and only Aluminium losses within a life cycle should be taken in account.

8 References

German case

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Danish case

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General

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19 LCA Manual from CML [1992].

20 Key feature document “How to treat aluminium in LCAs' the Aluminium Industry”.

21 EAA Environmental Profile Report for the European Aluminium Industry, EAA 1996, 2000.

22 Koch-Harnish report: Climate Change and energy supply systems for primary aluminium smelters- the allocation of CO_2 emissions to the electricity consumption in primary aluminium production, EcoFys, Matthias Koch and Jochen Harnish, may 2001.

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Legislation using LCA concerning Aluminium

Annexes

Report

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A Less relevant LCA aspects

In the matrix aspects that are considered as less relevant LCA aspects are mentioned. The choices and assumptions of the case study are listed under the heading 'description LCA aspect', the comments made by the stakeholders about the aspect are placed beneath.

Matrix 1a
Remarks on less relevant LCA aspects for aluminium, Danish and German case

Description	Aluminium packaging	
LCA aspect	Danish case	German case
system boundaries	extraction of the raw material, manufacturing of the material and packaging, distribution, waste management	complete system.
Data	Data are used from databases from 1990 - 1993	Database of EAA 1996 is used.
recycling percentages	90% recycling and 10% incineration 0% recycling and 100% incineration	75% of the aluminium cans are collected and recycled. The input of secondary Al in the can bodies is assumed to be 90%.
leading LCA methodology	conform EDIP method. 6 Impact categories are considered. One of those is waste.	Mostly conform ISO
Normalisation	normalisation to a person equivalent in 2000 (combination with distance-to-target)	normalisation to the average environmental impact of one person in Germany each year.

Comment by stakeholders	Aluminium packaging	
LCA aspect	Danish case	German case
system boundaries	The washing and filling is not considered. This can amout to 25%-30% of the total environmental impact.	no comment
Data	The used data are outdated. The effect of using old data for the environmental profile differs per material.	The critical review panel remarks that the data used for recycling are of low quality.
recycling percentages		no comment
leading LCA methodology	Waste is generally not considered as a separate LCA impact category. Rather the effects of landfilling or incineration attribute to tho other standard impact categories.	no comment
Normalisation	Normalisation to 2000 whilst data from 1990-1993 are used. Systematicly this incorrect.	no comment

Matrix 1b
Remarks on less relevant LCA aspects for aluminium, Dutch and Swiss case

Description	Aluminium building material	
LCA aspect	Dutch case	Swiss case
system boundaries	complete system	complete system
Data	Database of EAA 1996 is used.	database of EAA 1996 and Alcan are used
recycling percentages	94% of the aluminium construction products are reused. Of this 94% is 11% not recycleble.	90% - 95% of the facade sheets are recycled
LCA methodology	Mostly conform ISO	Mostly conform ISO
Normalisation	Normalisation on world emission data	Normalisation by relating emissions per product value to gross European Product

Comment by stakeholders	Aluminium building material	
LCA aspect	Dutch case	Swiss case
system boundaries	no comment	no comment
Data	no comment	no comment
recycling percentages	no comment	no comment
LCA methodology	no comment	Impacts related to landfilling are ignored The 6 waste criteria and liberated radioactivity in MJ are not conform ISO. Normally CO and NOx are assumed not to contribute to global warming. Classification factors of CH_4 and N_2O differ from normaly used factors.
Normalisation	no comment	This normalisation can be disputed. This type of normalisation is benificial for products with a high value (for exaple perfumes), and negative for products with a low value.

B Energy scenarios

B.1 Factors influencing electricity related CO_2-emissions

The contribution per unit of primary aluminium due to electricity consumption in the electrolysis of alumina is determined by two factors:

- Electricity consumed per unit of aluminum.
- Contribution to climate change per unit of consumed electricity.

Electrolysis of alumina is by far the most energy intensive process in primary aluminium production, requiring 14 kWh_e/ton for modern smelter with prebake anode cells to 18 kWh_e/ton for obsolete Søderberg cells. Average global consumption is approximately 15 kWh_e/ton primary aluminium and most smelters have a specific electricity consumption between 13.5 and 17 kWh_e/kg primary aluminium. All figures include off gas handling and anode production. As demonstrated by these figures the amount of electricity consumed per unit of aluminium shows relatively little variation between different smelters.

Contribution to climate change per unit of consumed electricity on the other hand can range from some 4 kg/Mh_e for electricity from hydropower to some 1,340 kg/MWh_e for electricity produced on the basis of brown coal. Contributions per unit of consumed electricity depend mainly on the nature of the energy source (hydropower, nuclear energy, and fossil fuels). In case electricity from fossil fuel fired power plants is consumed, power plant efficiency will also have a significant impact. Other factors with less influence on specific contribution are

- The chemical composition of the fired fossil fuel and related CO_2-emission per GJ fuel.
- Energy consumption and emission of greenhouse gases related to making the energy source applied in electricity consumption available.
- Transportation losses.

Variations in chemical composition of fossil fuels may give variations in CO_2-emissions per GJ fuel of up to ±10% from average. Consumption of energy carriers and direct emissions related to winning and transportation of energy sources used in power production can give contributions to greenhouse gas emissions of up to several tens of kg's of CO_2 per GJ of electricity consumed in alumina electrolysis. Since electrolysis cells consume medium voltage or high voltage power, transportation losses are only 1% - 2% and transformation losses are virtually zero.

Summing up, the size of CO_2-emissions from electricity consumed in electrolysis of alumina is mainly determined by the nature of the energy source applied in power production and power plant efficiency. Factors like specific electricity consumption, chemical composition of fossil fuels and making the power source applied in power production available have a minor impact. However, in accordance with the ISO 14040 framework these aspects should also be taken into account in LCA's or a founded statement should be made why these factors are neglected.

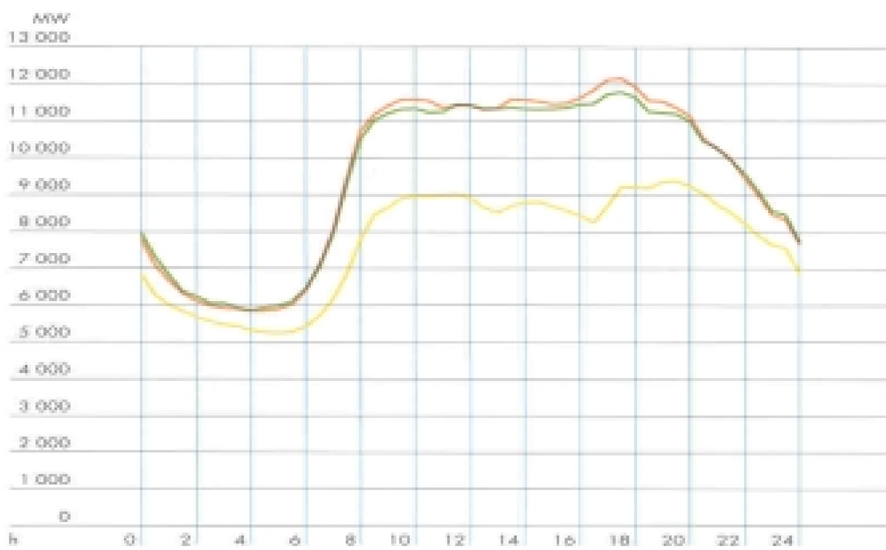
B.2 Variations in electricity supply structures

The nature of the energy source applied in power production and power plant efficiency's varying strongly between different countries or even regions.

Electricity supply is still mainly organised nationally or regionally (e.g. the Netherlands, Germany), with power being supplied by a national or regional operating provider. The natures of the energy source applied and power plant efficiency are determined by factors like availability of energy resources, local energy policy and market prices. For example, in regions with vast reserves of fossil fuels or large potential of hydropower will apply these resources if application is profitable. The choice to rely for 75% or more on nuclear energy for power production in France is largely politically motivated.

In most countries or regions more than one energy source is applied, with different energy sources playing different roles in electricity production. Three kinds of power plants can be distinguished, each with a different role in the strategy of electricity suppliers to cope with the fluctuations in electricity demand:
- Base load units.
- Medium load units.
- Peak load units.

Figure 8 Variation in Dutch electricity consumption from grid during the day (given for various years)



There is a constant consumption of electricity from continues industrial activities, such as electrolysis of alumina. This consumption is visible between 2 a.m. and 6 a.m. and is covered by base load units. Those units produce electricity almost continuously throughout the year and almost round the clock at full plant production capacity. Because start up and shutting down take more time than with other energy sources base load is mainly provided for by soft coal and hard coal fired power plants and nuclear power plants. In some regions hydropower (e.g. Iceland, Norway) and natural gas fired power plants (e.g. Netherlands) are also applied to cover based load demand. Only

in the Netherlands a non-neglectable part of base load consumption (15% - 20%) is covered by import of electricity. Other sources are waste incineration plants, renewable energy sources (wind, biomass) and dedicated power plants applying secondary energy carriers produced in industrial activities, such as blast furnace gas.
During the day overall consumption rises due to domestic activities and consumption from non-continues industrial activities. In order to deal with this increase, medium peak units – and in case of peak demand also peak load units - are started up and connected to the grid. Medium load capacity is provided for by gas fired and oil fired power plants and by storage water power plants. Another strategy may be varying production rate of coal fired power plants.

B.3 LCA's and actual Al production

From the previous paragraph it is clear that if the basic assumptions applied in an LCA with respect to electricity production for alumina electrolysis should represent reality as closely as possible, the origins of the considered aluminium should be determined. In other words, in which country/countries or region(s) is the considered aluminium produced. Information about the origins of aluminium consumed in a specific country is given by sources such as Metallgesellschaft, IPAI, EUROSTAT.

Electrolysis of alumina is a continues operation, consuming 100 MW_e for small plants (50 kton Al per year) to 400 – 500 MW_e for large plants (200 – 250 kton Al per year). So the second thing to determine would be what kind of base load units are applied in the region the considered aluminium stems from and/or how much is purchased from other producers.

After having determined region of origins and local power supply structure one can determine emission factors of CO_2 per kWh_e for the considered region and the base load units applied in that region.

In some specific cases it is even possible to identify a specific power plant supplying electricity to a specific smelter. In regions with a large potential of cheap electricity construction of a new aluminium smelter is or was often combined with the construction of a new power plant. The regional electricity supplier or authorities want to exploit the available resources as much as possible and attract large base load consumers of electricity. This is often the case in regions or countries with a high potential of hydropower and modest electricity consumption, such as Iceland, Canada, Brasilia. Other examples are the production sites of Pechiney and Aldel in the Netherlands[18]. For such a case CO_2-emissions per ton Al can be determined very specifically if specific electricity consumption for the considered smelter and specific CO_2-emissions per GJ_e supplied by the considered power plant are known.

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[18] The construction of the Pechiney aluminium smelter in Vlissingen is related to the stimulation of nuclear power in the Netherlands by the Dutch government, which subsidised construction and operation of the Borssele 12 nuclear power plant. The construction of the Aldel aluminium smelter in Delfzijl is connected to the desire of the Dutch government in the 1960's to consume the then recently discovered natural gas resources as quickly as possible. The Dutch government at that time feared that the natural gas resources would soon become worthless due to the prognosed abundance of cheap electricity from nuclear power plants.

Unfortunately, detailed information about the origins of the aluminium considered within the framework c.q. the system boundaries of a LCA or detailed information about local electricity supply structure is frequently not applied in LCA's or is not available to the researchers. In those situations researchers tend to apply a more general approach, such as using an average national electricity mix or an average European grid mix for determining greenhouse gas emissions.

B.4 Effects of assumptions on size of greenhouse gas emissions

The effects of the applied assumptions with regard to production of the electricity consumed in electrolysis of alumina are demonstrated for example by the calculations of Ecofys. They calculated the specific emissions for Western European primary aluminium production, using different approaches for the applied electricity mix:

- 5.0 kg CO_2-eq/kg Al for the dedicated power plant approach.
- 5.6 kg CO_2-eq /kg Al for the contract mix approach.
- 6.1 kg CO_2-eq /kg Al for the national mix approach.
- 7.8 kg CO_2-eq /kg Al for the average European grid mix approach.

The EAA [EAA] ecoprofile gives a specific emission of 5.9 kg CO_2-eq/kg Al. In the last three approaches applied by Ecofys [ecofys] the average CO_2 emission factor for the considered mix was applied, neglecting differences between CO_2 emission factors base load units and average CO_2 emission factors. Still, as demonstrated, differences can amount easily to 50% or more compared to the EAA ecoprofile.

Differences will be even larger when considering aluminium products in a specific country and applying dedicated plant or base load contract mix approaches for electricity production. For example, primary aluminium consumed in the Netherlands in products like window frames should have an emission factor of approximately 2.3 kg CO_2/kg Al.

> Approximately 60% of primary production comes from Pechiney Vlissingen, 40% from Aldel Delfzijl. The Borssele 12 nuclear power plant supplies Pechiney with electricity, Aldel receives electricity from Electrabel, the energy producer located in that region. Electricity supplied by Electrabel is produced at the Eems Centrale consisting of 5 gas fired combined cycles with an average efficiency of 55%. Specific CO_2-emissions are estimated at 4 kg/GJ for Borssele 12 and 102 kg/GJ_e for the Eems Centrale.
>
> Assuming a specific consumption of 14 kWh_e/ton Al for Pechiney and 15 kWh_e/ton Al for Aldel the average CO_2 emission factor for primary aluminium in the Netherlands is $3.6 \times (60\% \cdot 14 \cdot 4 + 40\% \cdot 15 \cdot 102) = 2{,}325$ kg CO_2/ton aluminium.

As demonstrated by both examples using an average national mix or average european mix approach for the specific greenhouse gas emission per unit of electricity can give results that grossly underestimate or overestimate the true specific emission.

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