ICCA - Worldwide Voice of the Chemical Industry

Reduction of Greenhouse Gas Emissions via Use of Chemical Products

Case Studies

Exemplifying the Application of the ICCA & WBCSD
Avoided Emissions Guidelines

INTERNATIONAL
COUNCIL OF
CHEMICAL
ASSOCIATIONS

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Foreword

The contribution of the chemical industry to GHG emissions reduction is well established. The reduction is achieved through the use of high efficiency processes and products – such as fuel-saving tires, LED lamps, insulation materials for buildings and solar cells.

Reducing GHG emissions during the manufacturing phase is one part of the contribution. Reducing the emissions during the use of the products is another and often more important part to realize the environmental benefit. Accounting for the reductions can however be complex and not always straightforward. Typically, the majority of chemical products are part of an assembly or more complex end products.

This leads to challenges when quantifying the GHG reductions enabled by chemical components/ingredients. The amount of the calculated GHG emissions (avoided emissions) depends greatly on the system boundaries used and the choice of the reference products.

The International Council of Chemical Associations (ICCA) and the World Business Council for Sustainable Development (WBCSD) Chemical Sector project have recognized the importance of establishing specific guidelines to help quantify and report the contribution of chemical products in reducing GHG emissions over the product life cycle. The guidelines' practical steps for their application were published in 2013.

The goal of the present report is to illustrate, through several examples offered by ICCA members and associations, how to apply the guidelines to individual cases. The second objective is to encourage chemical companies to apply the guidelines when calculating the avoided emissions of their products.
The evaluation of the avoided emissions must be carefully conducted, ensuring consistency and transparency.

We expect this report will help member companies and associations develop robust studies and further enhance the credibility of the chemical industry as solution provider for a low carbon economy.

Shigenori Otsuka
Chair of ICCA E&CC LG

Executive summary

The main purpose of this report is to exemplify the application of the ICCA & WBCSD Chemical Sector guidelines *"Addressing the Avoided Emissions Challenge: Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies"*.

It is expected to motivate other chemical companies to apply the guidelines and help them generate high quality case studies.

The objective of this technical report is to:

- Raise awareness about the emission reduction potential of chemical products
- Illustrate the application of the ICCA & WBCSD Chemical Sector guidelines
- Motivate other chemical companies to use the guidelines
- Promote full life cycle approach

Review procedure

The studies were adapted from original work by applying the ICCA and WBCSD Chemical Sector guidelines.

To ensure that the case studies comply with the ICCA & WBCSD guidelines, ICCA commissioned Ecofys to review the case studies.

Ecofys assessed the overall compliance with the guidelines. The summary of the review findings is presented for each case study.

Case studies

The case studies in this report were offered by seven companies and two associations. The following companies and associations contributed to this project.

1. BASF

External Thermal Insulation Composite System for the refurbishment of an existing detached house in Germany

Solutions to compare	➢ An existing house insulated using an external thermal insulation composite system (ETICS) based on expanded polystyrene (EPS) ➢ The market-average existing German house
Functional unit	The heating of an existing single family detached house in Germany at average room temperature of 19°C for 40 years (from 2011 to 2051)
Avoided emissions	The avoided emissions resulting from the use of an ETICS system based on EPS amount 141 ton CO_2e per house in a 40-year period

2. Braskem

Polypropylene (PP) Containers for Chocolate Drink Powder

Solutions to compare	➢ PP containers for packaging of chocolate drink powder in Brazil in 2010 ➢ Tinplate containers for packaging of chocolate drink powder in Brazil in 2010
Functional unit	Packing and preserving with a rigid material, 400g of chocolate drink powder
Avoided emissions	The avoided emissions resulting from the use of PP containers amount 0.12kgCO_2 per 400g of chocolate drink powder

3. Evonik

Feed additives - DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan in broiler and pig production

Solutions to compare	➢ Supplementation of broiler and pig feed with the amino acids DL-methionine, L-Lysine, L-Threonine and L-Tryptophan ➢ Soybean meal ➢ Rapeseed meal
Functional unit	1 kg of amino acid mix or the equivalent amount of amino acids provided by feed raw materials.
Avoided emissions	The emissions savings enabled by the use of supplemented feed for broiler production are 44 kg CO_2e per 1 kg of amino acid mix compared to soybean meal, and 30 kg CO_2e compared to rapeseed meal. The emissions savings of supplemented feed for swine production are 20 kg CO_2e per 1 kg of amino acid mix compared to soybean meal, and 3 kg CO_2e per 1 kg of amino acid mix compared to rapeseed meal.

4. India Glycols Ltd (IGL)

Bio-Mono Ethylene Glycol (MEG) from renewable source

Solutions to compare	➢ Bio-based Mono-Ethylene Glycol (bio-MEG) produced by IGL in India ➢ Petrochemical-based MEG (petro-MEG)
Functional unit	1 ton of MEG produced
Avoided emissions	Avoided emissions resulting from using bio-MEG are 407 kg CO_2e per MT MEG production

5. The Japan Carbon Fiber Manufacturers Association (JCMA)

Aircraft materials (CFRP, Carbon Fiber Reinforced Plastic) for weight reduction

Solutions to compare	➢ Aircraft that consist for 50 wt.-% of carbon fibre reinforced plastic (CFRP) ➢ Conventional aircraft that consist for 3 wt.-% of CRFP
Functional unit	One aircraft
Avoided emissions	The avoided emissions are 27 kton CO_2e per aircraft unit in a 10-year period.

6. Japan Chemical Industry Association (JCIA)

Materials for fuel efficient tires

Solutions to compare	➢ Fuel-efficient tires ➢ Conventional tires
Functional unit	Service life of one tire for driving a passenger car (30.000 km) Service life of one tire for driving a truck/bus (120.000 km).
Avoided emissions	The total avoided emissions per tire : 57 kg CO_2e for passenger cars (228 kg CO_2e per car) 442.3 kg CO_2e for a truck/bus (4423kg for a truck/bus).

7. SABIC

Multilayer Polyethylene Packaging Films

Solutions to compare	➢ Five layer polyethylene (PE) packaging film ➢ Conventional three layer PE packaging film
Functional unit	A thousand square meters of multilayer packaging film used for packaging a set of six beverage bottles.
Avoided emissions	Avoided emissions enabled by the five layer PE packaging film are 40 kg CO_2e per 1000 square meter of packaging film

8. Solvay

Engineering plastics for Vehicle light-weighting

Solutions to compare	➢ A specific, small, car part, an engine mount housing, made of Technyl ➢ An aluminium alloy engine mount housing.
Functional unit	Ensuring one attachment point between the engine/gearbox set and the vehicle structure in a small-medium size car, throughout the vehicle's lifetime (150 000 km).
Avoided emissions	The avoided emissions : 2.0 kg CO_2e per car

9. Sumitomo Chemical

Broiler production by Feed additive DL-methionine

Solutions to compare	➢ Broiler feed with_DL- Methionine supplementation ➢ Broiler feed without DL-Methionine supplementation
Functional unit	1 kg of broiler meat
Avoided emissions	The avoided emissions : 0.114 kg CO_2e per kg of broiler meat

Lessons learnt

There were some elements in the guidelines that were found to be less clear when applying them to concrete case studies. More specifically, the project recommendation is to revise these three elements of the guidelines:

- **Level in the value chain**
  Clear description on how to select the level in the value chain
- **Solution to compare**
  Addition of practical type of baseline for the end-use level
- **Data quality**
  More specific guidelines on the data quality assessment

In addition, there is ongoing discussion on the data accuracy and allocation for multi-product processes. The review also highlighted differences in the quality of the case studies and the approach to LCA by the different companies.

A main outcome of the project is to use the report as an educational material to develop robust and more transparent LCA case studies.

This report will be posted on ICCA internal WEB site (ICCA Connect) and is expected to be used among ICCA member companies. This report could also be shared with LCA professionals upon request.

Introduction

The 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), or COP21, will take place in December 2015 in Paris. The aim of COP21 is to reach a global agreement to combat climate change effectively, and to boost the transition towards resilient, low-carbon societies and economies.

The chemical industry is a key solutions provider for climate change mitigation. Many innovative chemical products enable greenhouse gas (GHG) emission reductions downstream in the value chain, e.g. lightweight materials for transportation and insulation materials for homes. These emission reductions outweigh higher GHG emission during the production phase in most cases. In this way, the chemical industry contributes to net greenhouse gas emission reductions (also referred to as avoided emissions) throughout society.

Through a collection of examples, ICCA showcases the chemical industry's contribution to the transition to a low-carbon society.

The case studies addressing the GHG avoided emissions (henceforward, case studies), published on this website were collected from various chemical companies and industry associations worldwide. All case studies followed the ICCA & WBCSD Chemical Sector guidelines *"Addressing the Avoided Emissions Challenge: Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies"* which were developed in 2013*. The guidelines include requirements, i.e. on how to choose the baseline (solution to compare) and how to deal with the attribution of avoided emissions along the value chain. The use of such sector wide guidelines increases consistent calculation and communication of avoided emissions and makes companies' findings transparent and more credible.

This technical report provides illustrative examples on the application of the ICCA & WBCSD guidelines which may further enhance understanding of the guidelines and promote their widespread application.

The studies presented on this website focus on the reduction of GHG emissions only. It is the intention of the ICCA to broaden the approach and include other environmental impacts, like water and land use, in future studies when the respective accounting methodologies become more mature. It is important to note that most of the present case studies investigated possible trade-offs to other environmental impacts when realising GHG emission reductions.

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* The guidelines can be found at:
http://www.icca-chem.org/en/Home/Newsroom/News-Archive/2013/new-roadmap-explores-technologies-that-improve-chemical-industry-energy-use1/

Aim of project

Through the publication of this technical report and these case studies, the ICCA would like to achieve the following objectives:

1. **Raise awareness about emission reduction potential of chemical products**: Raise the awareness of stakeholders, such as customers, investors, policy-makers and citizens, about the emission reduction potential enabled by chemical products when taking a life cycle perspective.

2. **Illustrate the application of the guidelines**: The case studies provide practical examples on how to apply the ICCA & WBCSD guidelines, and illustrate how to interpret some of the requirements. This may help other companies start using the guidelines and can help them structure their studies. The lessons learnt in the case studies will also be used to improve future versions of the guidelines.

3. **Motivate other chemical companies to use the guidelines**: The case studies will inspire and motivate other chemical companies and chemical industry associations to create and publish similar information. It is the intention of ICCA to complement the current case studies with additional ones over time. In this way, the collection of case studies will grow, and cover a broader range of chemical products from various geographical regions. Ultimately, value chain partners and companies from other sectors may apply the guidelines to their own business sector as well, which could lead to joint publications on the ICCA website and elsewhere. The findings from those studies could form a basis for estimating the total potential GHG emissions reductions by the chemical industry (and other sectors).

4. **Promote full life cycle approach**: With the case studies, the ICCA wants to promote the use of Life Cycle Assessment (LCA) and Life Cycle Thinking (LCT) as comprehensive decision-support tool and concept for the chemical industry and its stakeholders.

Review procedure

To ensure that the case studies presented on the ICCA website comply with the ICCA & WBCSD guidelines *"Addressing the Avoided Emissions Challenge: Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies"*, ICCA commissioned Ecofys* to review the case studies. The review period started in December 2014 and was concluded in November 2015. Ecofys' specific role was to determine if the case studies are in compliance with the ICCA & WBCSD guidelines with a special focus on the mandatory ("shall") requirements. The review process focused on the case study reports provided by the companies and industry associations. A review of the complete Life Cycle Assessment (LCA) model and a verification of the used data were not part of this review. More comprehensive background documents were not reviewed either.

Two feedback loops were included in the review process, i.e. the practitioners revised the case studies twice based on Ecofys' review findings. In the third and final review, Ecofys assessed the overall compliance with the guidelines. A summary of the main review findings is presented for each case study in chapter 5. For each case study it was checked if it meets 12 criteria which each comprise a subset of the mandatory requirements. Ecofys then provided recommendations to ICCA on which case studies to publish. The final decision to publish the case studies rested with the Energy & Climate Change (E&CC) Leadership Group of ICCA which took into account other factors such as coverage of geographical regions and application of chemical products. Consequently, and while the studies have to meet minimum requirements, not all the case studies published on the website are fully compliant with the guidelines.

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* http://www.ecofys.com

Guidelines and lessons learnt

1.1 Development of guidelines

The guidelines were developed with the aim to increase the consistency and credibility of avoided emissions estimates communicated by chemical companies about their products. The guidelines were developed by the International Council of Chemical Associations (ICCA) and the chemical sector task force of the World Business Council for Sustainable Development (WBCSD). They were published in October 2013. Case examples along with the full report *Addressing the Avoided Emissions Challenge: Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies* can be found on the ICCA website.

1.2 Lessons learnt

In general, the companies and industry associations that carried out the case studies perceived the ICCA & WBCSD guidelines as easy-to-use and helpful in decision-making with regard to avoided emissions calculations. The simplified approach was welcomed by the practitioners as it provides companies the possibility to broaden the scope of their study without increasing the time and resources needed for the study (as long as the solutions to compare contain identical life cycle elements). However, there were also some elements in the guidelines that were found to be less clear when applying them in concrete case studies, especially related to the level in the value chain and the baseline (solution to compare).

2.2. Level in the Value Chain

The guidelines describe two levels in the value chain at which a study can be carried out, namely the "chemical product level" and the "end-use level" (see page 17 of the guidelines). At the chemical product level, the study compares the environmental impact along the life cycle of the chemical product with an alternative product currently in the market (e.g. polyethylene films for packaging). At the end-use level, the study focuses on the contribution of the chemical product to the avoided emissions realised by a low carbon technology (e.g. light-weight automotive parts) that uses the chemical product instead of currently implemented technologies.

LCA studies can be conducted at different levels in the value chain without changing the scope. For example:

- LCA study can be conducted for tires from cradle-to-grave at the (chemical) product level. In this case, the fuel savings of fuel efficient tires are not included in the study.
- LCA study can be conducted for tires from cradle-to-grave at the end-use level (car level). In this case, the fuel savings of fuel efficient tires are included in the study.

In a few case studies the level in the value chain was confused with the scope of the LCA study (cradle-to-gate versus cradle-to-grave). The selection of the level in the value chain has consequences for further choices to be made, e.g. the selection of the baseline and setting system boundaries. In the current version, the guidelines do not clearly describe how to select the level in the value chain.

Solution to compare

The ICCA & WBCSD guidelines include requirements for selecting the solution to compare as this selection will largely influence the calculated avoided emissions. The guidelines prescribe one type of baseline for the end-use level, namely *"weighted average based on shares of all currently implemented technologies for the same user benefit (including the studied end-use solution to which the chemical product contributes)"* (page 19 of the guidelines). When using this baseline, the avoided emissions express the potential of the chemical product to further reduce GHG emissions in the current market. This requirement was not always fully implemented in the case studies:

- Many case studies were done at the end-use level but used a different baseline, namely comparing the solution of the reporting company to an alternative product in the market with a market share of >20%. Such a comparison also makes sense, and is in some situations also easier to apply, but conveys a different perspective. It shows the emissions that can be reduced when using a specific low-carbon technology that uses the chemical product instead of an alternative technology available in the market. The ICCA & WBCSD guidelines should include this comparison as an option and provide clear guidelines on how to make this comparison.
- A limited number of case studies calculated the avoided emissions at the end-use level for a chemical product that already had a market share of (nearly) 100% in a specific market, e.g. in a specific region or application. In those cases, the chemical product and the solution to compare are the same and one cannot speak of avoided emissions. However, such studies could still illustrate the emission reductions enabled by the chemical product.

Data quality

Data quality is an important aspect when comparing two solutions. When the data used for one solution is less representative, it becomes questionable if the comparison reflects the actual market situation. A number of case studies did not address data quality or they only addressed it at a high aggregation level. The ICCA & WBCSD guidelines require a data quality assessment in line with ISO or the GHG Protocol, but more specific guidelines on data quality assessment within the ICCA & WBCSD guidelines could help companies to address this issue sufficiently in their avoided emissions studies.

Brief description of case studies & review comments

Through a collection of examples, ICCA showcases the chemical industry's contribution to the transition to a low-carbon society. The case studies below were offered by the chemical industry, applying the ICCA and WBCSD guidelines published in 2013. The case studies are a sample of chemical products and do therefore not present the full range of chemical products and their applications.

1. BASF

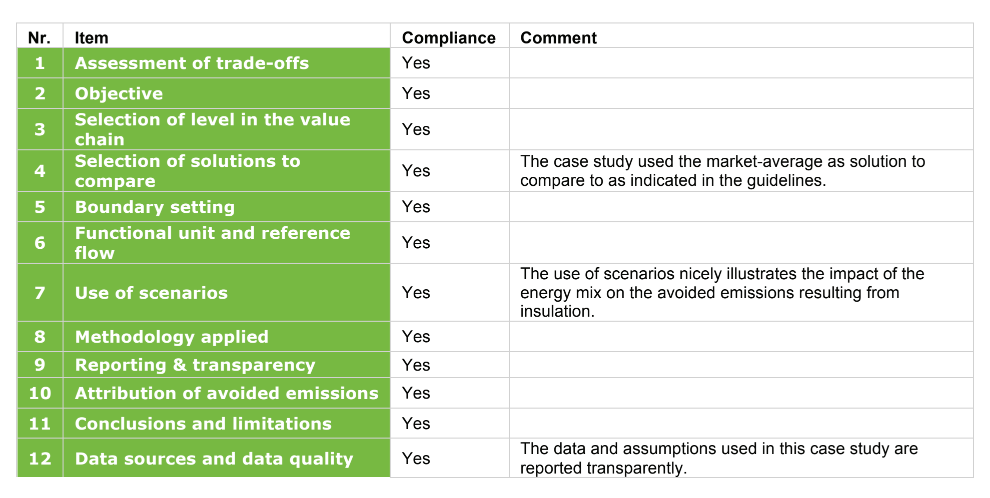
External Thermal Insulation Composite System for the refurbishment of an existing detached house in Germany

Brief description of case study

In this case study an existing house insulated using an external thermal insulation composite system (ETICS) based on expanded polystyrene (EPS) is compared to the (market-)average existing German house (e.g. based on 80% of non-refurbished houses and 20% already refurbished houses). The functional unit used in the case study is the heating of an existing single family detached house in Germany at average room temperature of 19°C for 40 years (from 2011 to 2051). The comparison takes place at the end use level. The avoided emissions resulting from the use of an ETICS system based on EPS amount 141 ton CO_2e per house in a 40-year period and are completely dominated by the reduced energy demand for heating the house during the use phase.

Review comments

The case study is in general of good quality and fully compliant with the guidelines. The market-average of refurbished and non-refurbished houses is adequately used as the solution to compare to. This case study reports very transparently about the data sources used and the assumptions made in the study. Given that heating represents the largest share of energy use in the residential buildings sector, there is a large potential for avoiding emissions. The case study indeed shows that the chemical solution has a high potential to reduce GHG emissions during the use phase of a house.



Nr.	Item	Compliance	Comment
1	**Assessment of trade-offs**	Yes	
2	**Objective**	Yes	
3	**Selection of level in the value chain**	Yes	
4	**Selection of solutions to compare**	Yes	The case study used the market-average as solution to compare to as indicated in the guidelines.
5	**Boundary setting**	Yes	
6	**Functional unit and reference flow**	Yes	
7	**Use of scenarios**	Yes	The use of scenarios nicely illustrates the impact of the energy mix on the avoided emissions resulting from insulation.
8	**Methodology applied**	Yes	
9	**Reporting & transparency**	Yes	
10	**Attribution of avoided emissions**	Yes	
11	**Conclusions and limitations**	Yes	
12	**Data sources and data quality**	Yes	The data and assumptions used in this case study are reported transparently.

2. Braskem

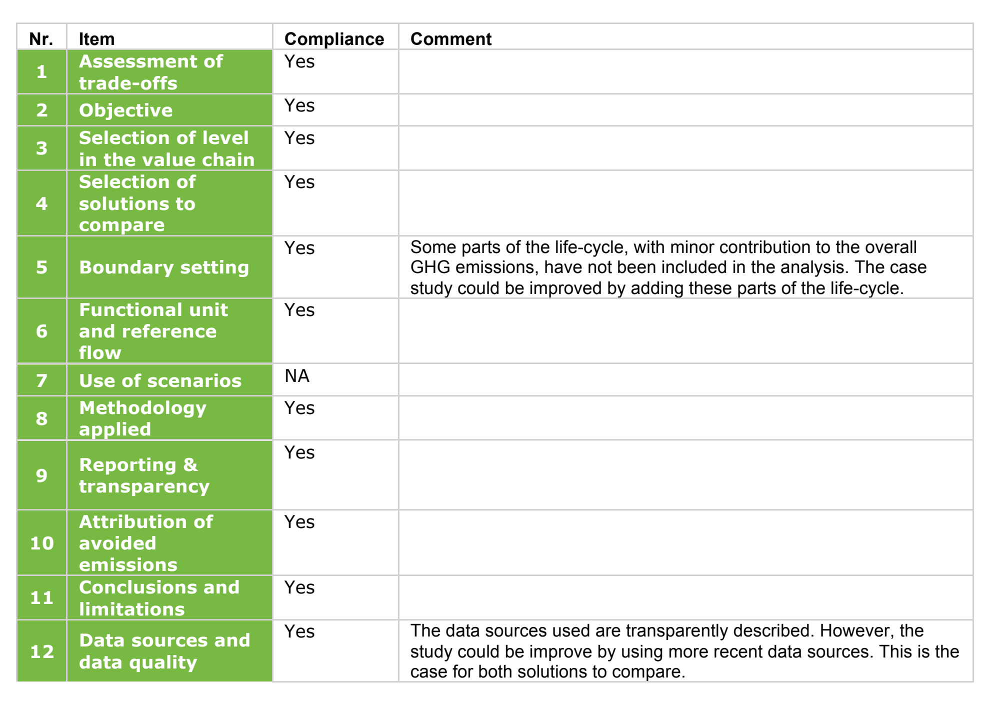
Polypropylene (PP) Containers for Chocolate Drink Powder

Brief description of case study

In this case study PP containers and tinplate containers for packaging of chocolate drink powder in Brazil in 2010 are compared at the chemical product level. The functional unit of the study is to pack and preserve, with a rigid material, 400g of chocolate drink powder. The study indicates the avoided emissions related to replacing tinplate by PP containers. The study finds that GHG emissions can be reduced by 56.36% when PP containers are used instead of tinplate containers. Total avoided emissions are found to be 10 $ktCO_2e$ in the Brazilian market in 2010.

Review comments

The case study is compliant with the guidelines. The solutions to compare and functional unit are adequately chosen as well as the level in the value chain. The data sources used in this study are transparently described. However, the study could be improved by using more recent data sources. This is the case for both solutions to compare. Moreover, some parts of the life-cycle, with minor contribution to the overall GHG emissions, have not been included in the analysis. The case study could be improved by adding these parts of the life-cycle.



Nr.	Item	Compliance	Comment
1	**Assessment of trade-offs**	Yes	
2	**Objective**	Yes	
3	**Selection of level in the value chain**	Yes	
4	**Selection of solutions to compare**	Yes	
5	**Boundary setting**	Yes	Some parts of the life-cycle, with minor contribution to the overall GHG emissions, have not been included in the analysis. The case study could be improved by adding these parts of the life-cycle.
6	**Functional unit and reference flow**	Yes	
7	**Use of scenarios**	NA	
8	**Methodology applied**	Yes	
9	**Reporting & transparency**	Yes	
10	**Attribution of avoided emissions**	Yes	
11	**Conclusions and limitations**	Yes	
12	**Data sources and data quality**	Yes	The data sources used are transparently described. However, the study could be improve by using more recent data sources. This is the case for both solutions to compare.

3. Evonik

Feed additives - DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan in broiler and pig production

Brief description of case study

In this case study supplementation of broiler and pig feed with the amino acids DL-methionine, L-Lysine, L-Threonine and L-Tryptophan is compared with soybean meal and rapeseed meal with the same nutritional value. The functional unit is 1 kg of amino acid mix or the equivalent amount of amino acids provided by feed raw materials. Avoided greenhouse gas emissions are realised by less use and cultivation of arable land for crop production (less CO_2 equivalent emissions from land transformation) and by less production of manure by animals (less N_2O emissions from manure storage and from application to the field). The emissions savings enabled by the use of supplemented feed for broiler production are 44 kg CO_2e per functional unit (1 kg of amino acid mix) compared to soybean meal, and 30 kg CO_2e compared to rapeseed meal. The emissions savings of supplemented feed for swine production are 20 kg CO_2e per functional unit compared to soybean meal, and 3 kg CO_2e per functional unit compared to rapeseed meal.

Review comments

The case study is a nice example of how feed additives can reduce GHG emissions compared to feed without additives. The study is largely in line with the ICCA & WBCSD guidelines except for a few aspects. The case study reports that the study is conducted at the chemical product level, while it is in fact an end-use level study (from cradle-to-farm gate). The use phase (consumption of feed) of the product (amino acid mix) is included in the study as well as the related avoided emissions. Additionally, the study describes some complex issues in a very concise manner, which makes the study sometimes hard to understand for the reader. One example is the used reference flow which is defined as the net difference between the different feeding options. Furthermore, the data quality and limitations of the study have not been addressed sufficiently.

Nr.	Item	Compliance	Comment
1	**Assessment of trade-offs**	Yes	It is not explicitly mentioned, but results on other environmental impacts are shown in the annex and do not show trade-offs (for almost all cases). It is still the question if all relevant impact categories are included in the study.
2	**Objective**	Yes	
3	**Selection of level in the value chain**	No	The level in the value chain is made explicit, but is not correct. The scope of the study is cradle-to-farm gate which includes the feeding of the amino acids to the animals as well as the reduction in manure compared to the solution to compare.
4	**Selection of solutions to compare**	No	Data quality is not specified for both solutions.
5	**Boundary setting**	Yes	Boundaries could be made more explicit in the diagram.
6	**Functional unit and reference flow**	Yes	Both time and geographical reference could be more clearly specified. Reference is made to section 6.1 for more information on time and geographical reference, but this information is not included in section 6.1.
7	**Use of scenarios**	N/A	
8	**Methodology applied**	Yes	The study could benefit from a more extensive explanation of the used methodology.
9	**Reporting & transparency**	No	Results are not differentiated per life cycle phase. The way of presenting results is not intuitive (negative impact due to approach using net differences) and might be difficult to interpret for the reader.
10	**Attribution of avoided emissions**	Yes	
11	**Conclusions and limitations**	No	Limitations are not addressed. The conclusion does not summarize the overall findings of the study.
12	**Data sources and data quality**	No	Data quality is not sufficiently addressed.

4. India Glycols Ltd (IGL)

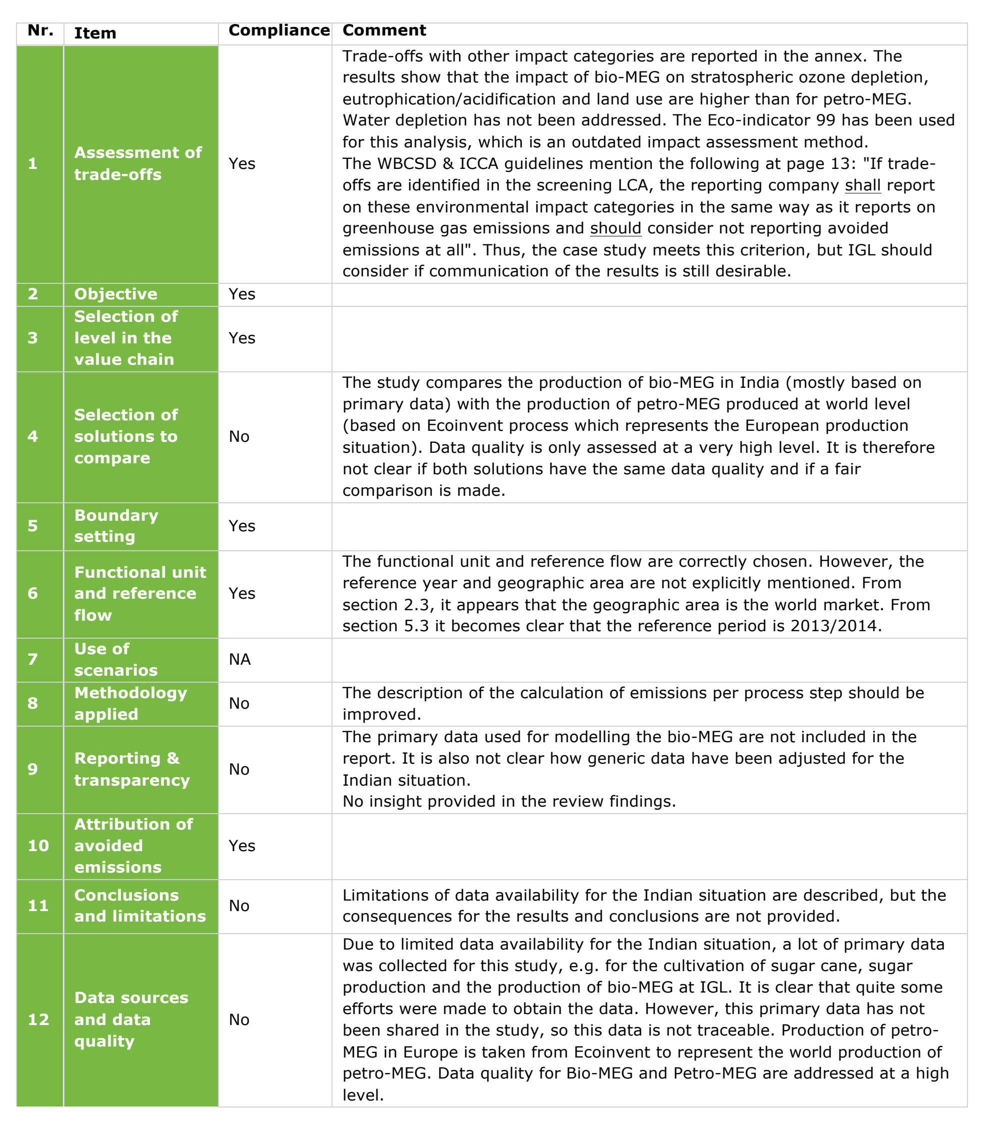
Bio-Mono Ethylene Glycol (MEG) from renewable source

Brief description of case study

The case study compares bio-based Mono-Ethylene Glycol (bio-MEG) produced by IGL in India with petrochemical-based MEG (petro-MEG) from cradle-to-gate at the chemical product level. The functional unit is defined as 1 ton of MEG produced, and the study takes place at the chemical product level. The bio-MEG is produced from agricultural renewable feedstock, namely sugarcane molasses. The production of bio-MEG results in lower GHG emissions compared to petro-MEG. Avoided emissions of using bio-MEG are 407 kg CO_2e per MT MEG production, which is predominantly the result of the use of bio-based feedstock. The study also reports that bio-MEG has a higher impact on acidification/eutrophication, compared to petro-MEG, due to the use of fertilizers for sugarcane cultivation.

Review comments

The function of bio-MEG and petro-MEG are the same and the case study has defined the functional unit correctly. The system boundaries are well-explained, and the study also selected the correct level in the value chain. The major gap in the study is the traceability of the data used to model the GHG emissions from bio-MEG of IGL. A lot of primary data was collected, but these data have not been included in the study. The adjustment of Ecoinvent data for the Indian situation are also not described in detail. Data quality assessment is only described at a high level. It is therefore questionable if the two solutions are compared on an equal basis (same data quality, same assumptions). The shift from petro-MEG to bio-MEG leads to a reduction in GHG emissions, but at the same time increases other impacts like acidification/eutrophication, ozone depletion and land use. Trade-offs to other impacts are correctly reported and are therefore in line with the ICCA & WBCSD guidelines, but it should be considered if communication is still desirable in case of trade-offs.



Nr.	Item	Compliance	Comment
1	**Assessment of trade-offs**	Yes	Trade-offs with other impact categories are reported in the annex. The results show that the impact of bio-MEG on stratospheric ozone depletion, eutrophication/acidification and land use are higher than for petro-MEG. Water depletion has not been addressed. The Eco-indicator 99 has been used for this analysis, which is an outdated impact assessment method. The WBCSD & ICCA guidelines mention the following at page 13: "If trade-offs are identified in the screening LCA, the reporting company shall report on these environmental impact categories in the same way as it reports on greenhouse gas emissions and should consider not reporting avoided emissions at all". Thus, the case study meets this criterion, but IGL should consider if communication of the results is still desirable.
2	**Objective**	Yes	
3	**Selection of level in the value chain**	Yes	
4	**Selection of solutions to compare**	No	The study compares the production of bio-MEG in India (mostly based on primary data) with the production of petro-MEG produced at world level (based on Ecoinvent process which represents the European production situation). Data quality is only assessed at a very high level. It is therefore not clear if both solutions have the same data quality and if a fair comparison is made.
5	**Boundary setting**	Yes	
6	**Functional unit and reference flow**	Yes	The functional unit and reference flow are correctly chosen. However, the reference year and geographic area are not explicitly mentioned. From section 2.3, it appears that the geographic area is the world market. From section 5.3 it becomes clear that the reference period is 2013/2014.
7	**Use of scenarios**	NA	
8	**Methodology applied**	No	The description of the calculation of emissions per process step should be improved.
9	**Reporting & transparency**	No	The primary data used for modelling the bio-MEG are not included in the report. It is also not clear how generic data have been adjusted for the Indian situation. No insight provided in the review findings.
10	**Attribution of avoided emissions**	Yes	
11	**Conclusions and limitations**	No	Limitations of data availability for the Indian situation are described, but the consequences for the results and conclusions are not provided.
12	**Data sources and data quality**	No	Due to limited data availability for the Indian situation, a lot of primary data was collected for this study, e.g. for the cultivation of sugar cane, sugar production and the production of bio-MEG at IGL. It is clear that quite some efforts were made to obtain the data. However, this primary data has not been shared in the study, so this data is not traceable. Production of petro-MEG in Europe is taken from Ecoinvent to represent the world production of petro-MEG. Data quality for Bio-MEG and Petro-MEG are addressed at a high level.

5. The Japan Carbon Fiber Manufacturers Association (JCMA)

Aircraft materials (CFRP, Carbon Fiber Reinforced Plastic) for weight reduction

Brief description of case study

This case study compares two aircrafts, one that consist for 50 wt.-% of carbon fiber reinforced plastic (CFRP) and one, conventional, that consist for 3 wt.-% of CRFP. CRFP can be used in various aircraft components and reduces the weight of the aircraft while maintaining the same strength and safety. The functional unit is one aircraft and the study is performed at the end-use level. The study shows that avoided emissions resulting from the increased use of CFRP are dominated by fuel savings in the use phase as a result of the weight reduction. The avoided emissions per aircraft unit are 27 kton CO$_2$e in a 10-year period.

Review comments

The case study is a nice example of how chemical solutions can reduce greenhouse gas emissions in society. The CFRP aircraft provides the same service as the conventional aircraft while reducing emissions. The study clearly describes the objective of the study and selects the correct solution to compare and the correct level in the value chain. However, the case study does not describe the system boundaries in much detail. It is also not clear from the study how the reduction in fuel use is calculated. The quality of the study could be improved by reporting more transparently about the choices made and the used calculation methodology. Moreover, the study could be improved by addressing the effect of future changes on the total amount of avoided emissions.

Nr.	Item	Compliance	Comment
1	**Assessment of trade-offs**	Yes	
2	**Objective**	Yes	
3	**Selection of level in the value chain**	Yes	
4	**Selection of solutions to compare**	Yes	The case study mentions that the market share of the CFRP aircraft is almost zero in 2009. The case study could be improved by mentioning that the market share for the conventional aircraft is nearly 100% in the same year.
5	**Boundary setting**	No	The case study provides one flow diagram for both aircrafts. The omission of disposal is not adequately justified. It is not explained if the treatment of the aircraft at the end of its lifetime has an influence on the avoided emissions. The life cycle of the aircraft could be described in more detail.
6	**Functional unit and reference flow**	Yes	
7	**Use of scenarios**	Yes	The study could be improved by describing how likely future changes may influence the avoided emissions.
8	**Methodology applied**	No	The study covers CO$_2$ only, while the guidelines prescribe it to include all greenhouse gases. It is not transparently reported how the reduction in fuel use is determined for the CFRP aircraft.
9	**Reporting & transparency**	Yes	The case study is very brief. Some more explanation would make the case study more transparent.
10	**Attribution of avoided emissions**	Yes	
11	**Conclusions and limitations**	Yes	
12	**Data sources and data quality**	No	Data quality is only described at a high level.

6. Japan Chemical Industry Association (JCIA)

Materials for fuel efficient tires

Brief description of case study

The case study of JCIA compares the GHG emissions of fuel-efficient tires with the emissions of conventional tires in Japan in 2010. The fuel-efficient tire has a lower rolling resistance, while keeping the same road-gripping performance, due to the specific formulation of the tire material, the structure of styrene-butadiene rubber (SBR) and the dispersion technology of higher amounts of silica in the rubber. The study calculates the GHG emissions savings for passenger cars and trucks/buses. The functional unit used in this study is the service life of one tire for driving a passenger car (30.000 km) and as the service life of one tire for driving a truck/bus (120.000 km). The comparison takes place at the end-use level. The total avoided emissions per tire are 57 kg CO_2e for passenger cars (228 kg CO_2e per car), and 442.3 kg CO_2e for a truck/bus (4,423 for a truck/bus). The largest part of the avoided emissions are realised during the use phase (driving the car).

Review comments

The case study is a good example of how chemical products can reduce GHG emissions in society while keeping the same lifestyle. The objective of the study, the solutions to compare, the functional unit and system boundaries are well-defined. The results are presented per life cycle stage, per tire and per vehicle. Limitations of the study are addressed concisely. However, the forecast of avoided emissions in 2020 are not described in the objectives of the study and are also not addressed in the functional unit. Future changes in energy-efficiency of cars is not quantified nor described, while changes could be expected. The used data are not included in the study; instead a reference is made to a Japanese source. It was not possible for the reviewer to check some data. The high fuel use of the vehicles could therefore not be checked, while this has a significant influence on the total avoided emissions.

Nr.	Item	Compliance	Comment
1	**Assessment of trade-offs**	Yes	
2	**Objective**	Yes	The description of the objective could be improved by clarifying that the study will not only compare the GHG emissions of fuel-efficient and conventional tires in Japan in 2010, but that the total avoided emissions potential in Japan in 2020 will also be calculated.
3	**Selection of level in the value chain**	Yes	
4	**Selection of solutions to compare**	Yes	
5	**Boundary setting**	Yes	
6	**Functional unit and reference flow**	Yes	The functional unit is defined as one tire (or one vehicle), and the results reflect this functional unit. However, the results also include the avoided emissions based on all fuel efficient tires in Japan in 2020. This is an inconsistency in the study.
7	**Use of scenarios**	Yes	The study could be improved by addressing how avoided emissions might change in the future e.g. by an increased efficiency of cars.
8	**Methodology applied**	Yes	Allocation of emissions and benefits of material recycling and energy recovery at the tire's end of life is not described in the case study. Although this is not an explicit requirement of the ICCA & WBCSD guidelines, the study could be improved considerably when this aspect is addressed.
9	**Reporting & transparency**	Yes	
10	**Attribution of avoided emissions**	Yes	
11	**Conclusions and limitations**	Yes	Conclusions can be more specific, mentioning that the study results indeed show that fuel-efficient tires reduce GHG emissions compared to conventional tires. It would also be informative to mention the amount of GHG emissions that can be reduced.
12	**Data sources and data quality**	Yes	The study could be improved by including the used data in the case study. Fuel consumption of the passenger car seems to be high (0.1 litre of gasoline per km for the conventional tire). A reference is provided in Japanese language, so it was not possible for the reviewers to check the correctness of this source. Data quality is described only very concisely.

7. SABIC

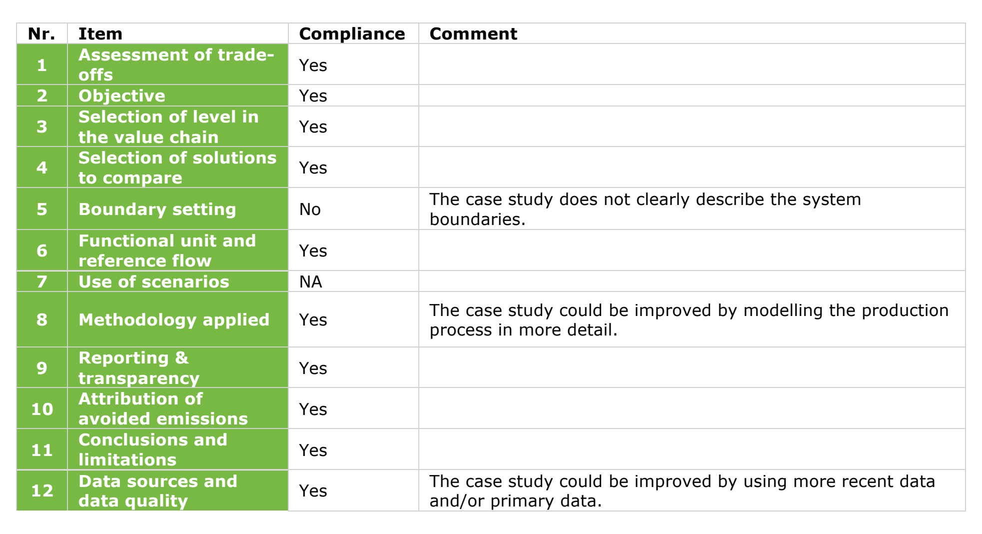
Multilayer Polyethylene Packaging Films

Brief description of case study

In this case study five layer polyethylene (PE) packaging film is compared¬ – at the chemical product level – to conventional three layer PE packaging film. The functional unit is a thousand square meters of multilayer packaging film used for packaging a set of six beverage bottles. Both solutions to compare are produced, marketed and consumed in Europe and the reference year for comparison is 2012. Five layer film allows a 22% reduction in film thickness compared to three layer film. The resulting reduction in material demand and waste are driving the emission savings. Avoided emissions enabled by the five layer PE packaging film are 40 kg CO_2e per 1000 square meter of packaging film compared to the conventional three layer PE packaging film.

Review comments

This case study is largely compliant with the guidelines. The solutions to compare and the functional unit are adequately chosen. The boundaries of the study could have been more explicitly set. The main limitation of this study is the use of secondary data, which are in some cases dated. The case study could be improved by modelling the production process in more detail and using more recent datasets.



Nr.	Item	Compliance	Comment
1	Assessment of trade-offs	Yes	
2	Objective	Yes	
3	Selection of level in the value chain	Yes	
4	Selection of solutions to compare	Yes	
5	Boundary setting	No	The case study does not clearly describe the system boundaries.
6	Functional unit and reference flow	Yes	
7	Use of scenarios	NA	
8	Methodology applied	Yes	The case study could be improved by modelling the production process in more detail.
9	Reporting & transparency	Yes	
10	Attribution of avoided emissions	Yes	
11	Conclusions and limitations	Yes	
12	Data sources and data quality	Yes	The case study could be improved by using more recent data and/or primary data.

8. Solvay

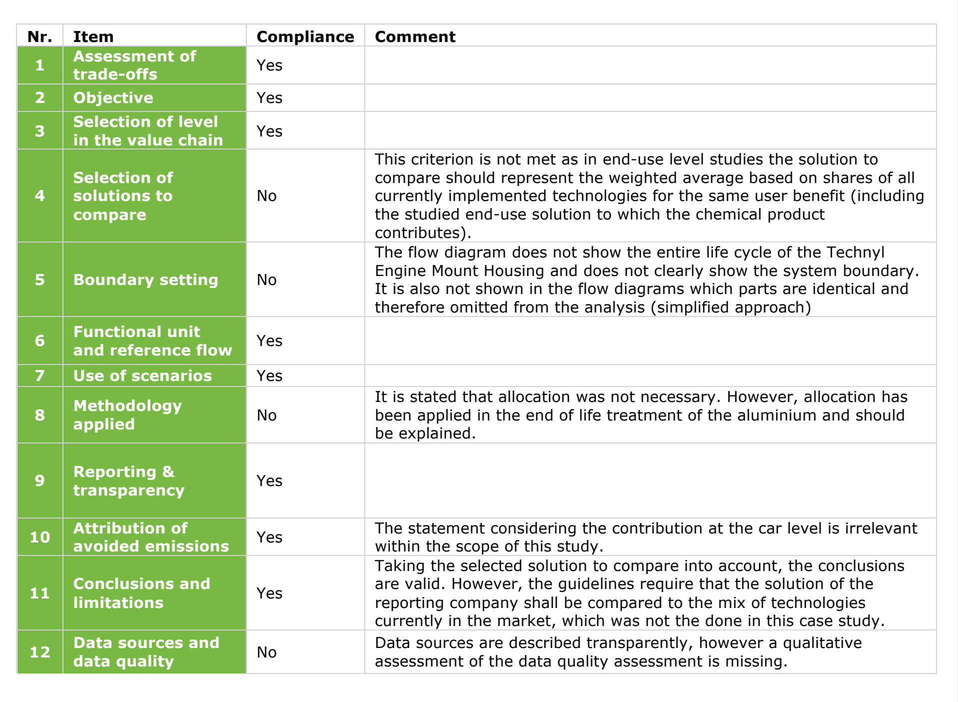
Engineering plastics for Vehicle light-weighting

Brief description of case study

This case study shows the potential of light-weight car parts in designing more fuel-efficient cars. The study focuses on a specific, small, car part, an engine mount housing, made of Technyl®, an engineering plastic, compared to an aluminium alloy engine mount housing. The study takes place at the end-use level and focuses on the specific car part (e.g. the remainder of the car is outside the system boundaries). The functional unit consists in ensuring one attachment point between the engine/gearbox and the vehicle structure in a small-medium size car, throughout the vehicle's lifetime. The study shows that the Technyl part enables avoided emission both through lower emissions in the production phase, and through reduced fuel consumption during the use phase (i.e. driving the car) as a result of the reduced weight. The avoided emissions ensured by this small car part represent as much as 2.0 kg CO_2e per car as compared to the aluminium-alloy-based solution of the Engine Mount Housing during its entire life cycle, and reach 5600 t CO_2e over the total production (estimated to be of 280 000 cars/year during 10 years) of the specific passenger car under study.

Review comments

In general, the study is of good quality. The study selected the correct level in the value chain (end-use level) and a valid functional unit. The solution to compare is not fully in line with the ICCA & WBCSD guidelines. For studies conducted at the end-use level, the guidelines recommend that the basis for comparison should be the weighted average of all solutions bringing the same user benefit on the market, based on their shares in the market (including the studied end-use solution, in this case the Technyl solution). Since substitution of the aluminium engine mount housing by the solution of the reporting company (Technyl) has already taken place in the specific car brand and type under study, this is not the case. However the case study is still good example of how light-weight car parts can and does reduce GHG emissions when driving a car.



Nr.	Item	Compliance	Comment
1	Assessment of trade-offs	Yes	
2	Objective	Yes	
3	Selection of level in the value chain	Yes	
4	Selection of solutions to compare	No	This criterion is not met as in end-use level studies the solution to compare should represent the weighted average based on shares of all currently implemented technologies for the same user benefit (including the studied end-use solution to which the chemical product contributes).
5	Boundary setting	No	The flow diagram does not show the entire life cycle of the Technyl Engine Mount Housing and does not clearly show the system boundary. It is also not shown in the flow diagrams which parts are identical and therefore omitted from the analysis (simplified approach)
6	Functional unit and reference flow	Yes	
7	Use of scenarios	Yes	
8	Methodology applied	No	It is stated that allocation was not necessary. However, allocation has been applied in the end of life treatment of the aluminium and should be explained.
9	Reporting & transparency	Yes	
10	Attribution of avoided emissions	Yes	The statement considering the contribution at the car level is irrelevant within the scope of this study.
11	Conclusions and limitations	Yes	Taking the selected solution to compare into account, the conclusions are valid. However, the guidelines require that the solution of the reporting company shall be compared to the mix of technologies currently in the market, which was not the done in this case study.
12	Data sources and data quality	No	Data sources are described transparently, however a qualitative assessment of the data quality assessment is missing.

9. Sumitomo Chemical

Broiler production by Feed additive DL-methionine

Brief description of case study

In this case study, two options for broiler feed with different protein contents are compared: a study feed supplemented with DL-Methionine and a control feed without DL-Methionine. Since methionine is the first limiting amino acid in broiler feed, the supplementation with DL-Methionine plays a key role to reduce nitrogen content in broiler feed. Reducing the nitrogen content in the feed is an effective way to reduce greenhouse emissions during manure management process by decreasing nitrogen excretion of the animal. The functional unit in this study is one kilogram of broiler meat and the geographical and temporal reference is Japan in 2011. The study shows that, while having a slightly higher impact in the raw material production, supplementing feed with DL-Methionine results in avoided emissions over the life cycle as a result of reduced nitrogen excretion. The estimated contribution of the study feed to GHG emission reduction was 0.114 kg CO_2e per kg of broiler meat, based on the difference in life-cycle GHG emissions between the two feed options.

Review comments

The chemical product under study, DL-Methionine, has a nearly 100% market share in Japan. The ICCA & WBCSD guidelines define the solution to compare at end-use level as follows (page 19 of the guidelines): the weighted average based on shares of all currently implemented technologies for the same user benefit (including the studied end-use solution to which the chemical product contributes). This implies that DL-Methionine is also the solution to compare, and one cannot speak of avoided emissions. However, the chemical product provides the opportunity to avoid emissions in other markets (outside Japan) where DL-Methionine has a lower percentage of the feed additive market share. Furthermore, the function of feed supplemented with DL-Methionine and unsupplemented feed as defined in the case study is as follows: produce the same amount of broiler meat in the same rearing period of 48 days. This function is reflected in the functional unit which is defined as one kg of broiler meat. Instead of using references or measurements, the case study assumes that this functional unit is fulfilled with the same amount of the two selected feed options which is not a strong basis for comparison.

Nr.	Item	Compliance	Comment
1	**Assessment of trade-offs**	Yes	The case study mentions that no trade-offs were found with other environmental impacts in the screening LCA. The results of the screening LCA are however not provided in the report.
2	**Objective**	Yes	
3	**Selection of level in the value chain**	Yes	
4	**Selection of solutions to compare**	No	If the study is conducted at the end-use level, the weighted average based on shares of all currently implemented technologies for the same user benefit (including the studied end-use solution to which the chemical product contributes) shall be used. The chemical product under study (DL-Methionine) already has nearly 100% market share in Japan, and therefore one cannot speak of avoided emissions. Therefore, the case study is not compliant with the guidelines in respect of this criterion.
5	**Boundary setting**	Yes	
6	**Functional unit and reference flow**	Yes	The study uses a functional unit of one kg of broiler meat which is well-chosen. The case study however assumes that both feed options fulfil this functional unit with the same amount of feed. This is not a strong basis for comparison. The study can be improved by using actual measurements or literature references, instead of assumptions, to underpin the required amount of feed for both feed options to arrive at one kg of broiler meat.
7	**Use of scenarios**	NA	The scenario analysis is only needed when a product has a long lifetime. Feed for broilers has no long lifetime, so a future scenario analysis is not necessary.
8	**Methodology applied**	No	The case study uses the simplified approach and omits some processes that are identical in the life cycle of both feed options. There is no information about the significance of the omitted processes on the total GHG emissions. The omission of certain GHGs in the calculation is not justified and is not in line with the guidelines.
9	**Reporting & transparency**	Yes	The report could be improved by making the used data sources and data quality more transparent (criterion 12). The functional unit and reference flows could also be described in a more transparent way (criterion 6). Other aspects are clearly described in the case study.
10	**Attribution of avoided emissions**	Yes	
11	**Conclusions and limitations**	No	Conclusions and limitations are largely in compliance with the ICCA & WBCSD guidelines, but since DL-Methionine has a nearly 100% market share in Japan, one cannot speak of avoided emissions. Limitations as a result of data quality are not addressed.
12	**Data sources and data quality**	No	Used data sources are mentioned, but a reference is not provided. Use of data for specific processes or ingredients are not mentioned. Data quality is not addressed.

Case study reports

Case 1 External Thermal Insulation Composite System (ETICS) for the Refurbishment of an Existing Detached House in Germany

BASF

COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned by BASF SE and performed by Nicola Paczkowski, BASF SE.

1. Purpose of the study

The purpose of this study is to provide the life cycle assessment (LCA) basis for calculating avoided emissions from chemical insulation materials to show and quantify their positive contribution to emissions reductions in the building sector. The study focuses on wall insulation of an existing house by using an External Thermal Insulation Composite System (ETICS) based on expanded polystyrene (EPS), a product of the chemical industry (Figure 1). The study does not intend to assess all technical possibilities to fulfill the defined user benefit such as different insulation materials, but instead compares a newly-insulated detached house with an average existing house. A more general goal of this study is also to understand and quantify the environmental impacts of the production, use and disposal of chemical insulation materials in the context of existing buildings within the limited scope of the study.

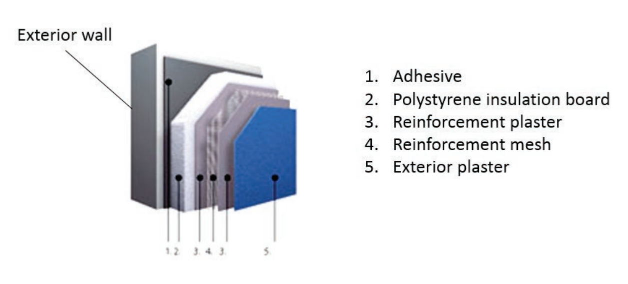
The study is a life cycle assessment including all material and energy inputs and outputs from raw materials acquisition through production, use and disposal (cradle-to-grave analysis). The study focuses on life cycle greenhouse gas emissions and follows the requirements of the Guidelines from the chemical industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies, developed by ICCA and the Chemical Sector Group of the WBCSD[1]. The study uses the simplified calculation methodology that omits identical parts in the life cycle of the solutions, which do not affect the absolute amount of avoided emissions. Hence the study does not include the construction and disposal of the house since this is identical for both alternatives.

2. Solutions to compare

2.1. Description of the solutions to compare

The study compares two alternatives for an existing detached house in Germany: one in which the house is left as is representing the weighted average of non-refurbished and already refurbished houses, and one in which the façade is refurbished to current German standards as described below using an External Thermal Insulation Composite System based on expanded polystyrene. EPS is a lightweight, rigid, plastic foam insulation material produced from solid beads of polystyrene made from styrene.

FIGURE 1 - EXTERNAL THERMAL INSULATION COMPOSITE SYSTEM (ETICS) BASED ON EXPANDED POLYSTYRENE



The solutions that are compared were selected on the basis of the following facts:

A. 83% of all buildings in Germany are detached or semi-detached houses (this corresponds to 59% of the total living area in Germany)[2]; thus the chosen building type of the case study represents the largest share of buildings in Germany. For more information on the selected house, please see section 12.1 in the Appendix.

B. Only about 20% of the existing detached and semi-detached house stock in Germany has been refurbished with wall insulation[3]; hence the implemented mix of technologies is currently 80% non-insulated houses and 20% insulated houses.

C. For the house that is left as is an average U-value* of 0.96 W/(m^2*K) for an exterior wall of a single family detached house in Germany was assumed. This value was calculated taking into account the following elements:

   1. For 80% of the living area, the average U-value (wall) of all existing single family homes in Germany that were built before 2011 was considered, which was defined to be the reference period. The average U-value was calculated as the sum of weighted U-values based on the relevant square meters of living space for the different building categories based on information of the German Institut Wohnen und Umwelt GmbH (IWU)[4].
   2. For 20% of the living area, which is the share of total houses that was refurbished before 2011, an average U-value (wall) of 0.3 W/(m^2*K) was

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* A U-value is a measure of heat loss in a building element.

assumed. The U-value of 0.3 W/(m^2*K) was derived as the mean of U-values required by the German Energy Savings Regulation (EnEV) for the time period before 2011[5].

The chosen approach refers to a comparison to the weighted average based on the shares of all currently implemented technologies.

D. For the newly-refurbished house a U-value (wall) of 0.2 W/(m^2*K) was selected since this value fulfills the requirements of the German Energy Savings Regulation 2009 (EnEV 2009)[6], in effect since 2009, for the renovation of existing buildings and at the same time qualifies for participation in the KfW Bankengruppe loan and subsidy program[7], a well-established and frequently used loan program in Germany.

E. The U-values of the other construction components of the house (roof, windows and floor) that also affect the heating energy demand of the house but with equal impact on the different alternatives were selected according to the current requirements of the EnEV 2009[6] for the refurbishment of buildings, again in conjunction with the criteria of the KfW Bankengruppe loan and subsidy program[7] (see Table A4 in the Appendix). Consequently, these building elements are state-of-the-art with a high thermal insulation.

2.2. Level in the Value Chain

The study focuses on a single family detached house with different degrees of thermal wall insulation. Thus, the level in the value chain is the end-use level according to the Guidelines from the chemical industry. This chosen calculation level is the lowest possible level closest to the chemical solution which still allows the comparison of the two alternatives.

The chemical product the study focuses on is expanded polystyrene. EPS is made from styrene and pentane as blowing agent to form a foam with excellent thermal insulation properties.[8] As part of an ETIC System it is used to improve the thermal insulation of outer walls, thereby reducing the amount of energy needed for heating the house. Other components of an ETICS are a base coat, adhesives, reinforcements and a finishing coat, all delivered by a system holder and applied on site.[9]

2.3. Definition of the boundaries of the market and the application

About 80% of the existing detached and semi-detached houses in Germany are still not insulated.[3] EPS, the main component of the exterior wall insulation system, has been used for several years in ETICS in the German market[10] and its market share is 87% based on sales volume of square meters in 2010.[11] The only other material that is used in ETIC Systems is stone wool.[11]

3. Functional unit and reference flow

3.1. Functional unit

Description of the function of the solutions to compare: Existing single family detached house in Germany with an average room temperature of 19°C.

Functional unit: Heating an existing single family detached house in Germany at average room temperature of 19°C for 40 years (from 2011 to 2051).

Quality requirements:

- *Functionality*: The main function of the studied solutions is to maintain an internal temperature of 19°C. This is achieved by both alternative solutions by means of solely burning fuel to generate heat or by using exterior wall insulation in conjunction with a lower consumption of heating fuel.
- *Technical quality*: Both solutions are stable and durable. The heating systems need to be maintained in both alternatives; the ETIC System does not need any specific maintenance. ETIC Systems are used for more than 40 years. They do not have any underlying shortcomings.[9] With proper care for example painting of the façade, their lifetime is as long as the lifetime of the building.[10]
- *Additional services rendered during use and disposal*: Besides repainting, the ETIC System needs to be disposed of at the end of its life; this was considered in the life cycle assessment. A ventilation system to remove moisture in well-insulated buildings is often recommended, in particular in passive houses. However, the implementation rate of ventilation systems in existing buildings is still very low[3] and thus was not considered in the analysis. Nonetheless, ventilation heat losses due to conventional ventilation of rooms were taken into account (see Table A4 in the Appendix).

Service life:

The service life was defined to be 40 years. The lifetime of the insulation material is not limited to 40 years and may be as long as the lifetime of the building.[10] A service life of 40 years was chosen in accordance with the assessment system for sustainable buildings, developed by the German Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety in collaboration with the German Sustainable Building Council (DGNB)[12].

Time and geographical reference:

The reference year of the study is 2011. Homes that were built until the end of 2010 are referred to as existing buildings. The geographic region chosen is Germany.

3.2. Reference flow

The applied reference flows are:

- The newly-insulated house with 198 m^2 of an External Thermal Insulation Composite System with an EPS Board (WLG 035 (lambda = 0.035 W/(m*K), density 20 kg/m3) with a thickness of 14 cm achieving a U-value (wall) of 0.2 $W/(m^2*K)$ and a net heating energy demand of 10,018 kWh/a (for more information, please see Tables A4, A6 and A8 in the Appendix).
- The house left as is with a net heating energy demand of 20,875 kWh/a (for more information, please see Tables A6 and A7 in the Appendix).

4. Boundary setting

- Production of the ETIC System: The ETIC System consists of an EPS foam board as the main component which is made from EPS beads provided by the chemical industry. EPS is manufactured from styrene, a liquid petrochemical, in the presence of small amounts of pentane (blowing agent) and a flame retardant (HBCD). Converters expand and mold the EPS beads to form boards or blocks by means of steam.[8] Besides EPS, the ETIC System contains adhesive, dowels, reinforcement plaster, reinforcement mesh and exterior plaster.[9] Aluminum profiles are used to ensure a secure mechanical fixing of the ETICS.[10]

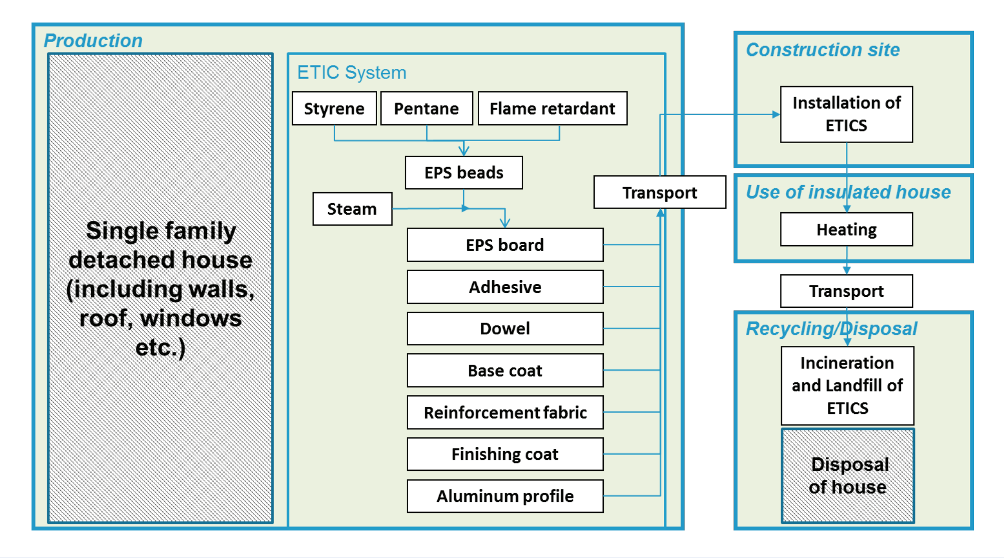
- Installation of the ETIC System: The ETIC System is assembled at the construction site.[9] All material and waste flows linked to the installation were included in the analysis. Only the energy requirements, such as the electricity for drilling the dowel holes were excluded since their contribution to the total energy demand of the product system was assumed to be negligible.

- Use of the house: The house is heated to obtain an average internal temperature of 19°C. The house does not have air conditioning, i.e. no cooling of the house in hot weather occurs since less than 1% of the houses in Germany are equipped with air-conditioning[3]. The energy carriers used represent the current heating structure in detached and semi-detached houses of the existing building stock in Germany based on the numbers of buildings with the respective heating system[3] (see Table A5 in the Appendix).

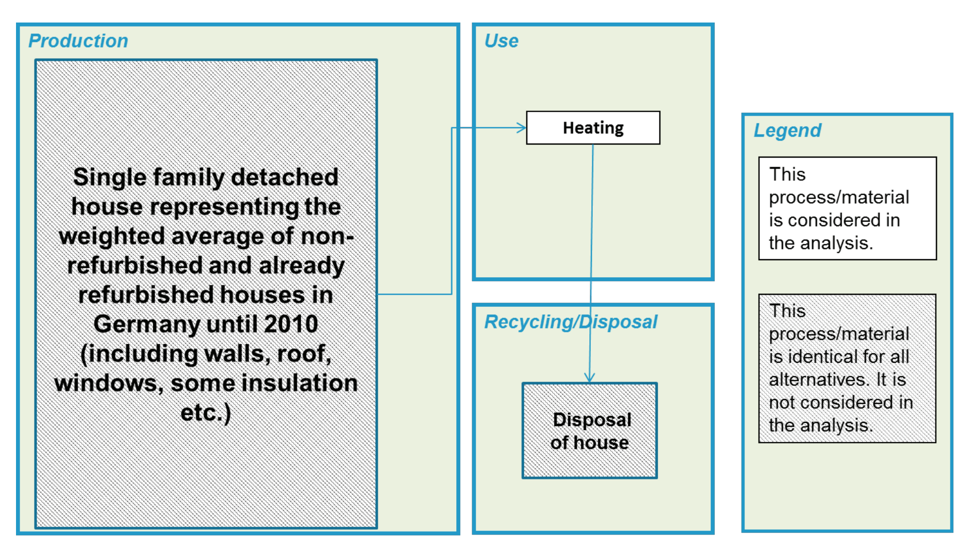
- Disposal: At the end of the defined service life, disposal of the ETIC System is necessary. 90% of the EPS is incinerated with energy recovery, while the remaining components are landfilled.[9]

- Transports of materials to and from the construction site were included in the study (see Table A9 in the Appendix). The wall insulation of the house which represents the weighted average of non-refurbished and already refurbished houses was not taken into account because of the small amounts of materials needed and their negligible impact on the results of the study as can be concluded from the results in section 6. In any case, its consideration would increase the environmental impact of the respective alternative, leading to higher avoided emissions.

SYSTEM BOUNDARY AND PROCESS MAP FOR HOUSE WITH NEWLY-INSTALLED ETIC SYSTEM



SYSTEM BOUNDARY AND PROCESS MAP FOR HOUSE LEFT AS IS



5. Calculation methodology and data

5.1. Methods and formulas used

This study is a life cycle assessment including all material and energy inputs and outputs from raw materials acquisition through production, use and disposal (cradle-to-grave analysis). Although the study focuses on life cycle greenhouse gas emissions, other environmental impact categories were assessed as well such as acidification potential, ozone creation potential, ozone depletion potential, primary energy demand, resource consumption, water emissions, solid wastes and land use. The environmental impact categories were evaluated according to BASF's Eco-Efficiency methodology[13], which follows the ISO norms 14040:2006 and 14044:2006 for life cycle assessment. For GHG emissions the impact method used was IPCC 2007 GWP, with characterization factors for a time frame of 100 years [IPCC 2007][14].

In this study the simplified calculation method was used. This means that the production and disposal phases of the study do not consider the entire house, but only the differences between the two alternatives. These are the production and the installation of the ETIC System and the disposal of the insulation system at the end of its defined service life. Construction and disposal of the house are identical for the two alternatives and their non-consideration does not change the overall conclusion of the study as shown in the Appendix, section 12.2. In addition these data are very complex and difficult to obtain. The omitted GHG emissions of the construction and disposal of the house represent 13% of the total emissions of the house left as is (see section 12.2). The omitted emissions were estimated by adding available life cycle impact assessment (LCIA) results for the construction and demolition of a single family detached house (built in 1997 in Belgium) to the base case results of the study. The data were derived from a comprehensive LCA study on insulation in buildings conducted by PricewaterhouseCoopers (PwC) in 2013.[15]

5.2. Allocation

No allocation was needed in the documented input data. Nevertheless, some of the life cycle inventory (LCI) data (secondary data from databases) used to model the pre-chains include assumptions concerning allocation. These assumptions are documented in the corresponding databases.

5.3. Data sources and data quality

In this study, primarily secondary data available from literature, previous LCA studies, and life cycle databases were used for the analysis. The LCI data for the upstream production processes of the materials, for energy carriers, electricity as well as for the disposal of the materials were taken either from the Boustead database (The Boustead Model, Version 5.0, expanded with company-specific data), from the European reference Life Cycle Database (ELCD 3.1) or from Ecoinvent v2.2. For more information on data sources, please see the Appendix, section 12.3.

Overall, the quality of the data used in this study is considered by the author of this study to be sufficient and appropriate for the described solutions. The quality of the secondary data taken from literature to model the house (heating system, energy mix, components of the ETIC System etc.) is considered to be good and representative of the described system to represent the average technology used in Germany. The quality of the secondary data from the three life cycle databases Boustead, ELCD and Ecoinvent to model the upstream processes is reduced by possible inconsistent system boundaries of the databases and by the age of some data sets. However, individual data quality measures are applied in all three databases to ensure coherent and appropriate quality data. For more information on data quality, please see the Appendix, section 12.3.

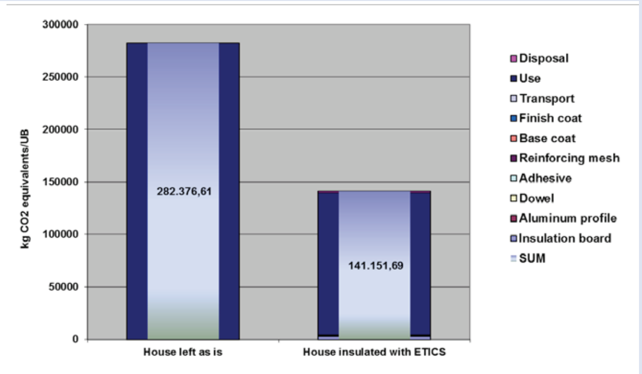
6. Results

6.1. Avoided emissions

Figure 2 shows the cradle-to-grave GHG emissions of the detached house in Germany over 40 years left as is in comparison to the house with modern façade insulation. The newly-insulated house has a significant lower carbon footprint than the house left as is.

The results are clearly dominated by the use phase, that is the combustion of heating fuel with associated GHG emissions. The impact of the manufacture and disposal of the ETIC System is very small and hence not visible in Figure 2. Key parameters of the study that have the most significant impact on the use phase and hence on the level of avoided emissions include the service life of the insulation material and the lifetime of the building, the type and mix of energy carriers for heating the house, the efficiency of the heating system and the heat loss of the walls defined by their U-value.

FIGURE 2 - GRAPH SHOWING THE RESULTS OF THE CASE STUDY



The avoided emissions are the difference between the GHG emissions of the house left as is and the house newly-insulated with the ETIC System. All involved partners along the value chain have contributed to this emission reduction.

As mentioned in Section 5.1 other environmental impact categories besides greenhouse gas emissions were assessed in the study as well. In all of the categories considered the newly-insulated house causes a lower environmental impact than the house left as is; hence no trade-offs exist.

6.2. Scenario analysis

Since the use phase of this study covers a time period of 40 years (from 2011 to 2051), a number of changes are expected to occur over this timespan. Uncertainties mainly exist with regard to the fuel mix for meeting the heating energy demand of the house, the heating system itself, the service life of the product or the lifetime of the building. Looking at the policy goal of meeting the 2 degree C target, it is anticipated that in the long-term a significant change of the energy and building sector will take place. This will have a remarkable impact on the results of this study meaning that the value for the GHG emissions avoided will most likely be significantly reduced. A continuous change is already taking place in the area of modernization of heating systems (modernization rate at about 2-4% per year in Germany), which is often linked to a change in the energy carrier away from coal and oil to gas or biomass.

Scenario 1 evaluates the effect of a changing energy mix away from fossil-based fuels to biomass and non-biomass renewable energy on the results of the study. It considers a low-carbon energy carrier mix as defined by WWF for the year 2050 (“Scenario 2050”)[16] and at the same time an assumed efficiency of the heating systems of 98 to 100%. Table 2 shows significantly reduced avoided emissions compared to the base case.

TABLE 1 - REPRESENTING THE RESULTS OF THE CASE STUDY IN KG CO_2e PER USER BENEFIT/SOLUTION

Emissions per life cycle phase	Reporting company’s solution [kg CO_2e]	Solution to compare to [kg CO_2e]
Production - EPS insulation board	2,565.8	0
Production - Aluminium profile	551.7	0
Production - Dowel	253.4	0
Production - Adhesive	287.6	0
Production - Reinforcing mesh	91.9	0
Production - Base coat	258.5	0
Production - Finish coat	177.8	0
Distribution	80.6	0
Use phase - Heating	135,513.7	282,376.6
End of Life	1,370.8	0
Total emissions	**141,152 (P1)**	**282,377 (P2)**
Avoided emissions	**= P2 – P1 = 141,225**	

TABLE 2 - REPRESENTING THE RESULTS OF SCENARIO 1 IN KG CO_2e PER USER BENEFIT/SOLUTION WITH MODIFIED ENERGY MIX

Emissions along the entire life cycle	Reporting company's solution [kg CO_2e]	Solution to compare to [kg CO_2e]
Total emissions	**41,781 (P1)**	**75,313 (P2)**
Avoided emissions	**= P2-P1 = 33,532**	

Scenario 2 evaluates a reduced building lifetime of 30 years. The results in Table 3 demonstrate that the avoided emissions are proportionally reduced and hence about a quarter less than in the base case.

TABLE 3 - REPRESENTING THE RESULTS OF SCENARIO 2 IN KG CO_2e PER USER BENEFIT/SOLUTION WITH REDUCED BUILDING LIFETIME

Emissions along the entire life cycle	Reporting company's solution [kg CO_2e]	Solution to compare to [kg CO_2e]
Total emissions	**107,273 (P1)**	**211,782 (P2)**
Avoided emissions	**= P2-P1 = 104,509**	

7. Significance of contribution

The focus product of this study, namely the expanded polystyrene, fundamentally contributes to the GHG emissions avoidance effect of the solution since it is the key component in the ETIC System, providing the thermal insulation function and thus significantly reducing the energy demand for heating the house. However, is must be noted that without the other components of the ETIC System and the many services along the supply chain (such as blowing the EPS beads to form the EPS boards, the adhesive that keeps the insulation material on the wall or the construction worker who actually applies the insulation to the wall) as well as the home owner who pays for everything, the wall insulation would not be possible. Therefore the efforts of various partners along the value chain contribute to the avoided emissions.

8. Review of results

A critical review (but not a panel review)[17] of the underlying Eco-Efficiency Analysis was carried out by DEKRA Consulting GmbH in July 2013.

9. Study limitations and future recommendations

The present study analyzes just one of the many aspects in the low-energy modernization of a house and in this context only the impact of a chemical solution. This simplified approach does not (necessarily) reflect the current practice and thus limits the applicability of the study. The study is based on specific conditions and assumptions that were selected to demonstrate an average situation for Germany. Consequently the study results may not be transferable to other locations and/or conditions that might be present in an actual case.

The results of this analysis are dominated by the use phase, i.e. the heating energy demand of the house and the service life. Therefore these results are very sensitive to the applied heating mix and the underlying energy carriers, the efficiencies of the heating systems, the lifetime of the house as well as to the climatic conditions of the location of the studied house. Thus the conclusions of this study cannot be applied unreservedly to other conditions. The results of the study should be seen within its limited boundaries and thus shall only be used in an appropriate manner in accordance with the goal and scope of the study.

10. Conclusions

This study compares the environmental performance of an existing detached house, once left as is representing the weighted average of non-refurbished and already refurbished houses in Germany and once with a new wall insulation system (ETICS) based on expandable polystyrene over a lifetime of 40 years. The main focus of the study was on the contribution of chemical insulation products as part of a wall insulation system to GHG emissions reductions. The results of the study within its limited scope clearly demonstrate the environmental benefits of wall insulation in particular with regard to the reduction of GHG emissions. The newly-insulated house has a significant lower carbon footprint as the house left as is with about 141 tons of avoided greenhouse gas emissions. The GHG emissions are dominated by the use phase, i.e. the heating energy demand of the house and the service life. Since conventional energy sources will continue to play a major role over the coming years, energy efficient solutions such as wall insulation are important measures to reduce energy consumption. This saves resources, reduces carbon dioxide emissions and also offers a large economic potential.

11. References

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EnEV 2009 requires a U-value (wall, max) of 0.24 W/(m2*K). Before 2009, the EnEV 2007 (2002) was in effect requiring an U-value (wall, max) of 0.35 W/(m^2*K) in refurbished homes.

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[15] PU Europe, April 2013: “Environmental and economic analysis of insulation products in low energy buildings”, a study conducted by PwC.

[16] Blue print Germany – A strategy for a climate safe in 2050, a study conducted on behalf of WWF, Germany, prepared by PROGNOS/Öko-Institut and WWF. Heating structure of detached and semi-detached existing buildings in Germany in the year 2050 (Scenario “Innovation”).

[17] The review statement is provided on request. A panel review was not deemed to be necessary as the reference case or product for comparison, respectively, does not comprise a competing product such as another insulation material.

[18] BASF Wohnen+Bauen, 2013, personal communication.

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12. Appendices

12.1. House data

The dimensions and geometry of the house including the number and size of windows were chosen to represent a typical single family detached house in Germany built in the 1960s. According to reference**[4]**, single family detached houses built in the 1960s represent the largest share of detached houses in Germany based on living area.

TABLE A1 - SUMMARY OF BUILDING GEOMETRY[18]

Geometric parameter	Value and Unit
Building envelope	406 m^2
Building volume	510 m^3
Heated air volume	387.6 m^3
Living area	163.2 m^2
Surface/volume ratio	0.8

TABLE A2 - BUILDING GEOMETRY – SURFACES AND THEIR ORIENTATION[18]

No	Decription	Orientation	Calculation	Area (gross)	Area (net)	Area percentage
				m^2	m^2	%
1	Attic	0.0°		91.0	91.0	22.4
2	Basement floor	0.0°		91.0	91.0	22.4
3	Exterior wall North	N 90.0°		72.8	65.5	16.1
4	Window North	N 90.0°	6*1.21*1.01	-	7.3	1.8
5	Exterior wall East	E 90.0°		39.2	37.98	9.4
6	Window East	E 90.0°	1.21*1.01	-	1.22	0.3
7	Exterior wall South	S 90.0°		72.8	60.4	14.9
8	Window South	S 90.0°		-	12.4	3.1
9	Exterior wall North	N 90.0°		39.2	33.7	8.3
10	Window North	N 90.0°		-	5.5	1.4

TABLE A3 - ENVELOPING SURFACES[18]

Wall	Exterior Wall Surface	Windows	
		Share	Surface
Exterior wall North	72.8 m^2	10%	7.3 m^2
Exterior wall East	39.2 m^2	14%	5.5 m^2
Exterior wall South	72.8 m^2	17%	12.4 m^2
Exterior wall West	39.2 m^2	14%	5.5 m^2
Basement floor	91 m^2	-	
Attic	91 m^2	-	

TABLE A4 - SUMMARY KEY PARAMETERS

Key parameter	Newly-insulated house	House left as is	Unit	Source/Reference
Internal temperature of house	19		degree C	[18]
Façade, insulation area	198		m^2	[18]
U-value (wall)	0.20	0.96	W/(m^2*K)	[7]/own calculations based on [4] and [5]
U-value (window)	0.95		W/(m^2*K)	[7]
U-value (roof)	0.14		W/(m^2*K)	[7]
U-value (floor)	0.25		W/(m^2*K)	[7]
Thickness of insulation material	14	-	cm	[18]
Density of insulation material	20	-	kg/m^3	[19]
Amount of EPS	582.1	-	kg	Own calculations
Adhesive	4.5	-	kg/m^2	[9]
Dowel	8	-	Pieces/m^2	[9]
Reinforcement mesh	1.1	-	m^2/m^2	[9]
Reinforcement plaster	4	-	kg/m^2	[9]
Exterior plaster	3	-	kg/m^2	[9]
Aluminum profile	0.14		kg/m^2	[18]
Service life of house	40		years	[12]
Heat loss from air out	92.25		W/K	[18]
Heating energy demand of house	See Table A6		-	[18]
Mix of energy carriers	See Table A5		-	[3]
Efficiency of heating systems	See Table A5		-	[20]

TABLE A5 - MIX OF ENERGY CARRIERS[3] AND ASSUMED EFFICIENCIES OF HEATING SYSTEMS[20]

	Share in %	Efficiency heating system
District heating	2.1	-
Natural gas	50.3	85%
Oil	35.9	85%
Biomass (wood)	6.3	75%
Coal	0.7	85%
Electricity (thereof 2% heat pump)	4.8	-

TABLE A6 - SUMMARY HEATING REQUIREMENTS[18]

	U-value wall [W/(m2*K)]	Thickness of insulation board [cm]	Final heating demand* [kWh/a]
Wall left as is	0.96	-	20,875
Wall newly insulated	0.20	14	10,018

*Excluding warm water

The thickness of the insulation board and the heating demand of the house for the two alternatives (foreground system) were calculated by in-house experts from BASF Wohnen+ Bauen, a subsidiary of BASF, for the purpose of this study. The Hottgenroth Software (Energieberater 18599 3D Plus 7.4.0 - Hottgenroth Software; calculation method: "Jahres-Heizwärmebedarf des Gebäudes mittels Monatsbilanzierung") was used to determine the heating demand of the two alternatives on the basis of the selected house and its monthly energy balance.

TABLE A7 - ENERGY BALANCE OF BUILDING LEFT AS IS REPRESENTING THE WEIGHTED AVERAGE OF NON-REFURBISHED AND ALREADY REFURBISHED HOUSES (U-VALUE (WALL) = 0.96 $W/(M^2*K)$)[18]

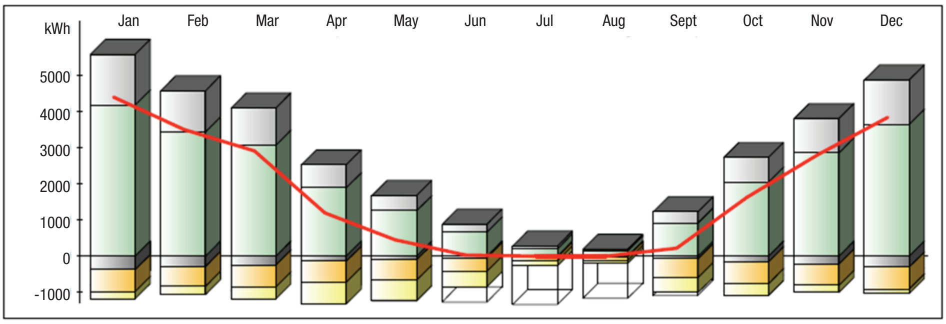
ENERGY LOSSES

Heat losses in kWh/month												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Transmission heat losses												
Transmission losses	3555	2911	2610	1610	1068	559	175	123	780	1734	2424	3100
Thermal bridge losses	613	502	450	278	184	96	30	21	134	299	418	535
Total	4169	3413	3060	1888	1253	656	205	144	914	2033	2842	3635
Ventilation heat losses												
Ventilation losses	1393	1141	1023	631	419	219	69	48	306	679	950	1215
Reduced heat losses by turning off/down heat at night												
Reduced heat losses	-367	-287	-240	-142	-94	-49	-15	-11	-69	-153	-221	-301
Total heat losses												
Total heat losses	**5195**	**4266**	**3842**	**2377**	**1577**	**826**	**259**	**181**	**1151**	**2559**	**3570**	**4548**

ENERGY GAINS (WITHOUT HEATING)

Heat gains in kWh/month												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Internal heat gains												
Internal heat gains	607	548	607	588	607	588	607	607	588	607	588	607
Solar heat gains												
Window N 90°	22	32	52	95	125	148	154	108	72	51	27	15
Window E 90°	6	9	14	31	34	37	40	30	22	13	7	4
Window S 90°	146	144	209	347	311	329	353	293	291	212	137	86
Window W 90°	29	39	61	140	152	168	181	133	101	59	31	17
Solar heat gains	203	223	337	613	622	682	728	564	486	335	202	123
Total heat gains in kWh/month												
Total heat gains	**811**	**772**	**944**	**1201**	**1229**	**1270**	**1335**	**1171**	**1074**	**942**	**789**	**730**

SUMMARY ENERGY BALANCE



Results of the monthly balance procedure

Annual heating needs = 20.875 kWh/(m²a)

Surface-related
annual heating needs = 127,91 kWh/(m²a)

Volume-related
annual heating needs = 40,93 kWh/(m²a)

Number of heating days = 274,6 d/a

Heating degree days = 3.501 Kd/a

- — Heating needs
- ▩ Ventilation heat losses
- 🟩 Transmission heat losses
- ■ Reduction of heat losses (interruption of heating etc.)
- 🟧 Usable internal heat gains
- 🟨 Usable solar heat gains
- ☐ Non usable heat gains

TABLE A8 - ENERGY BALANCE OF NEWLY-INSULATED BUILDING (U-VALUE (WALL) = 0.20 W/(M^2*K))[18]

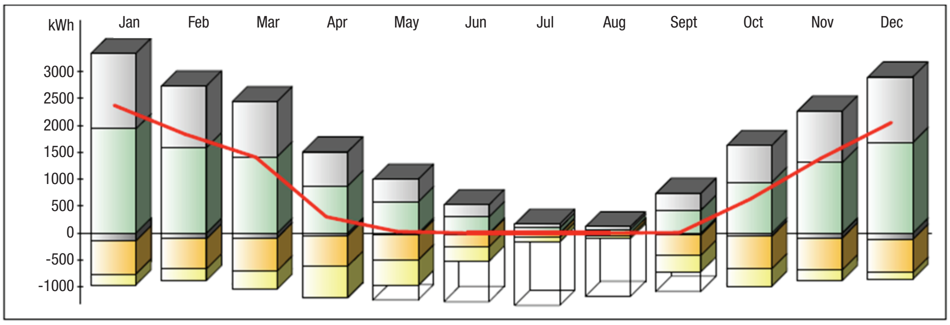
ENERGY LOSSES

Heat losses in kWh/month												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Transmission heat losses												
Transmission losses	1314	1076	965	595	395	207	65	45	288	641	896	1146
Thermal bridge losses	613	502	450	278	184	96	30	21	134	299	418	535
Total	1928	1578	1415	873	579	303	95	66	423	940	1314	1681
Ventilation heat losses												
Ventilation losses	1393	1141	1023	631	419	219	69	48	306	679	950	1215
Reduced heat losses by turning off/down heat at night												
Reduced heat losses	-144	-111	-91	-52	-35	-18	-6	-4	-25	-56	-83	-115
Total heat losses												
Total heat losses	**3177**	**2608**	**2347**	**1452**	**963**	**504**	**158**	**111**	**703**	**1563**	**2181**	**2780**

ENERGY GAINS (WITHOUT HEATING)

Heat gains in kWh/month												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Internal heat gains												
Internal heat gains	607	548	607	588	607	588	607	607	588	607	588	607
Solar heat gains												
Window N 90°	22	32	52	95	125	148	154	108	72	51	27	15
Window E 90°	6	9	14	31	34	37	40	30	22	13	7	4
Window S 90°	146	144	209	347	311	329	353	293	291	212	137	86
Window W 90°	29	39	61	140	152	168	181	133	101	59	31	17
Solar heat gains	203	223	337	613	622	682	728	564	486	335	202	123
Total heat gains in kWh/month												
Total heat gains	**811**	**772**	**944**	**1201**	**1229**	**1270**	**1335**	**1171**	**1074**	**942**	**789**	**730**

SUMMARY ENERGY BALANCE



Results of the monthly balance procedure

Annual heating needs = 10.018 kWh/(m^{2}a)

Surface-related
annual heating needs = 61,38 kWh/(m^{2}a)

Volume-related
annual heating needs = 19,64 kWh/(m^{2}a)

Number of heating days = 229,6 d/a

Heating degree days = 3.271 Kd/a

- ━ Heating needs
- ⬜ Ventilation heat losses
- 🟩 Transmission heat losses
- ⬛ Reduction of heat losses (interruption of heating etc.)
- 🟧 Usable internal heat gains
- 🟨 Usable solar heat gains
- ☐ Non usable heat gains

TABLE A9 - CONSIDERED TRANPORT DISTANCES AND MODES[21]

Transport	**Distance**	**Type of vehicle**
EPS beads to converter	200 km	Lorry, 40t
Insulation boards to construction site	200 km	Lorry, 40t
Other materials to construction site	200 km	Lorry, 7.5t
Insulation boards to disposal	26.5 km	Lorry, 22t
Other materials to disposal	15.5 km	Lorry, 22t

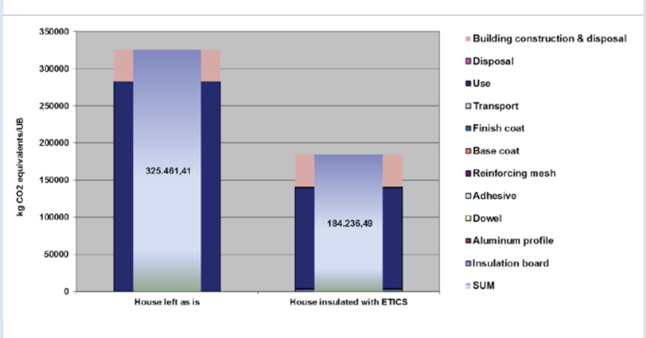
12.2. Evaluation of the impact of considering construction and disposal of the house on the results of the study

TABLE A10 - RESULTS OF THE STUDY INCLUDING CONSTRUCTION AND DISPOSAL OF THE HOUSE IN KG CO_2e PER USER BENEFIT/SOLUTION

Emissions per life cycle phase	**Reporting company's solution [kg CO_2e]**	**Solution to compare to [kg CO_2e]**
Construction and disposal of house	43,085*	43,085*
Production ETICS	4,186.6	0
Transport ETICS	80.6	0
Disposal ETICS	1,370.8	0
Use phase	135,513.7	282,376.6
Total emissions	**184,236 (P1)**	**325,461 (P2)**
Share of omitted emissions in relation to total emissions	23%	13%
Avoided emissions	**= P2 – P1 = 141,225**	

*According to reference [15]

FIGURE A1 - GRAPH SHOWING THE RESULTS OF THE STUDY INCLUDING CONSTRUCTION AND DISPOSAL OF THE HOUSE



The results of this evaluation show that the total life cycle GHG emissions are still driven by the energy consumption in the use phase, which remains the dominant factor of the study. Thus, not considering the GHG emissions from construction and disposal of the house does not change the overall conclusion of the study, moreover due to the fact that these processes are identical for the two alternatives and the absolute emissions avoidance remains the same. However, it is acknowledged that by omitting the construction and disposal of the house, the results of the impact assessment do not represent total but only major impacts.

12.3. Data sources and data quality

- Time-related coverage: In this analysis, primarily secondary data available from literature, previous LCA studies, and life cycle databases were used (see Tables A11 and A12). Only the heating energy demand of the house and the thickness of the insulation material were calculated for the purpose of the study. The upstream process data used mainly represent a time period from 2006 to 2012 but some process data refer back to the year 2000 and before.
- Geographical coverage: The geographical coverage of this study is Germany. However, some of the used upstream process data refer to the EU-27 (averaged data for Europe) or to Switzerland.
- Technology coverage: The study considers state-of-the-art processes for the production of the ETICS components, their disposal and for the extraction of the energy carriers. The heating technology represents the average technology used in Germany in the reference year.

TABLE A11 - OVERVIEW OF TIME REFERENCES AND DATA SOURCES

Input Data	Time Reference	Reference
Heating energy demand of house	2013	[18]
Area and thickness of insulation material	2013	[18]
Lifetime of insulation system	2013	[12]
Density of insulation material	2013	[19]
U-value (wall) per building class	2005	[4]
Living area per building class	2011	[4]
Share of refurbished detached houses	2010	[3]
U-value of insulated house	2013	[7]
U-value of other buildings components	2013	[7]
ETIC System components	2011/2013	[9], [18]
Efficiency of heating systems	2009	[20]
Mix of energy carriers	2010	[3]
End-of-life scenario	2011	[9]

TABLE A12 - LCI BACKGROUND DATA

(DATA SOURCES, QUALITY, GEOGRAPHICAL AND TIME-RELATED COVERAGE)

Data	Database	Year	Region	Quality*
EPS beads, white	PlasticsEurope	2006	Europe	High
Hexabromocyclododecane (HBCD)	Boustead	2008	Europe	High
EPS board production	Boustead	2009	Europe	High
Aluminum profile	Boustead	2000	Europe	Medium
HDPE	PlasticsEurope	2007	Europe	High
Stainless steel	ELCD	2007	Europe	Medium
Adhesive	Boustead	2008	Germany	Medium
Reinforcing mesh	Boustead	2008	Germany	Medium
Base coat	Boustead	2009	Germany	High
Fishing coat (organic)	Boustead	2009	Germany	High
Lorry transport	ELCD	2005/2007	Europe	High
Incineration with energy recovery	Ecoinvent v2.2	2000	Switzerland	Medium
Landfill	Ecoinvent v2.2	2000	Switzerland	Medium
Natural gas use	Boustead	2001	Germany	Medium
Light fuel oil use	Boustead	2001	Germany	Medium
Coal use	Boustead	2001	Germany	Medium
District heating	ETH-ESU	1996	Switzerland	Low
Heat from wood	Ecoinvent v2.2	2003	Switzerland	Medium
Electricity	Ecoinvent v2.2	2007	Germany	High

*Based on the qualitative data quality assessment scheme of the GHG Protocol Product Standard, September 2011

Completeness check: All relevant processes regarding the different life cycle phases were considered and modeled in accordance with the goal and scope definition of the study and the defined system boundaries.

Consistency check: The data, methods and assumptions applied throughout the analysis were selected to ensure consistency and allow consistent statements.

Case 2 Polypropylene (PP) containers for chocolate drink powder

Braskem

COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned by Braskem
and executed by ACV Brasil.

1. Purpose of the study

The objective of this study is to determine the reduction of GHG emissions by the use of Polypropylene (PP) resins for chocolate drink powder rigid container, when compared to tinplate containers.

This study has been prepared using the *"Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies (guidelines)"* developed by ICCA and the Chemical Sector Group of the WBCSD.

2. Solutions to compare

2.1. Description of the solutions to compare

Only rigid packaging alternatives are analysed. This is due to the fact that flexible containers, such as stand-up-pouches, are used for refill purposes and do not perform exactly the same function as rigid containers.
PP containers are blow moulded and the lids are injected, both using virgin only resin since the use of recycled material is not allowed in Brazil when the packaging comes into contact with food products. Tinplate containers are welded and a layer of varnish is applied. The filling process of the packages is assumed as being equal for both alternatives. The use (and eventual re-use) of the packages is also considered as being equivalent
All alternatives considered in this study fulfil the same function and meet the minimum requirements concerning the mechanical, safety and food preservation properties, established and controlled by the National Health Surveillance Agency [ANVISA 1999].

2.2. Level in the Value Chain

The study focuses on the use of PP resin for a chocolate drink powder rigid container. The study is based on the **chemical product level** to show the contribution of this chemical product for GHG emission reduction as a packaging solution.

2.3. Definition of the boundaries of the market and the application

The market for chocolate drink powder packaging (for 400g of product) in Brazil is dominated by the tinplate alternative, with 240.67 million units produced in 2010 (47.5%), followed by the analyzed fossil PP alternative, with 86.95 million units produced in 2010 (17.2%) [DataMark 2012]. Others represent 35.3% [DataMark 2012] and are not considered because, as flexible packaging, they do not fit in the rigid category under investigation.

3. Functional unit and reference flow

3.1. Functional unit

The function of the solutions compares is to pack and preserve chocolate drink powder with a rigid material. The functional unit has been set as to pack and preserve, with a rigid material, 400 g of chocolate drink powder, which is the actual size of one such container.

Both alternatives considered in the study fulfil the same function. The market considers that both alternatives provide the same shelf-life for the chocolate drink powder (one year), therefore the technical performance of the systems are equivalent.

All data are representative of the Brazilian market in year 2010.

3.2. Reference flow

The reference flows of the alternatives are described in the Table below and refer to the mass of each part of one individual container. The container were divided into body, lid (the tinplate alternative has a Low Density Polyethylene – LDPE lid), seal (to preserve the integrity of the packed product) and label where other information is displayed. The label is glued to the body.

PP Containers	Tinplate Containers
Polypropylene body: 26,31 g	Tinplate body: 63,26 g
Polypropylene lid: 7,27 g	LDPE lid: 7,25 g
Laminated seal: 1,22 g	Aluminium seal: 0,85 g
Paper label: 2,41 g	Paper label: 2,78 g

4. Boundary setting

This study covers the following life cycle stages:

- Extraction of Raw Materials and intermediate manufacturing, for both product systems;
- Manufacturing of the containers;
- Distribution;
- Use;
- Disposal of the containers.

Both packages are filled in the same way. Therefore package filling process has been disregarded in this comparative analysis. This was due mainly to lack of data, but this process has a relatively small contribution to the overall environmental impact. The main environmental aspect in the filling process is the use of electricity in the filling process, but given the characteristics of the Brazilian electricity matrix (over 85% hydro-powered) the related impacts in GHG emissions are low.

Infrastructure has not been considered for either product system due to the high level of uncertainty in these datasets and because usually these processes have low contribution to the final results.

All alternatives considered in this study fulfill the same function and meet the minimum requirements regarding mechanical properties, safety and food preservation, established and controlled by the National Agency for Sanitary Surveillance (ANVISA). It is also assumed that they have no differentiation during the use phase.

Figures 1 and 2 shows flow diagrams for both product systems.

FIGURE 1 - PRODUCT SYSTEM FOR TINPLATE CONTAINERS

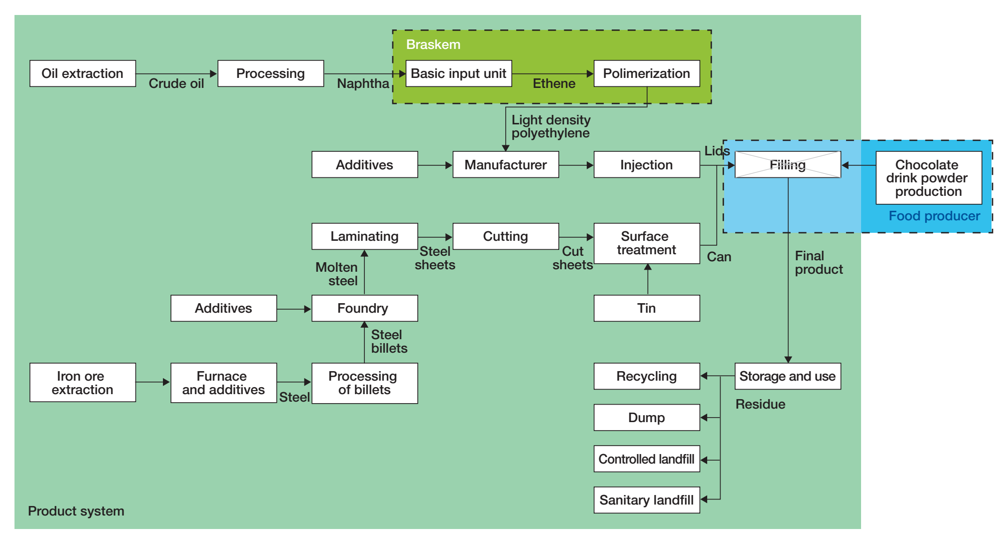
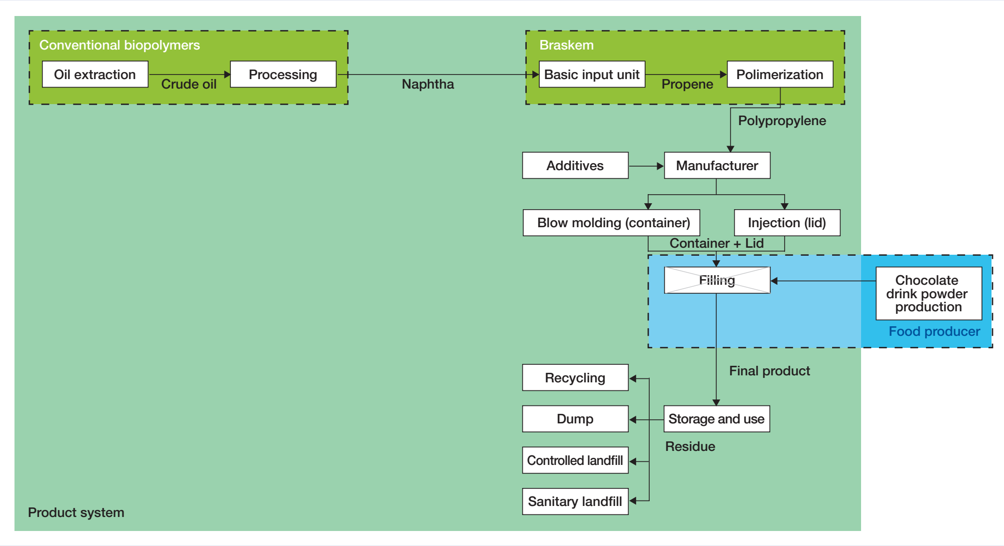


FIGURE 2 - PRODUCT SYSTEM FOR POLYPROPYLENE (PP) CONTAINERS



5. Calculation methodology and data

5.1. Methods and formulas used

Avoided GHG emissions were calculated as the difference between the life cycle emissions of PP containers and tinplate containers.

Modeling and calculations were made using SimaPro® software version 7.3. The impact method used was IPCC 2007 GWP, with characterization factors for a timeframe of 100 years [IPCC 2007].

5.2. Allocation

Allocation points are mainly upstream in the crude oil refining process and steam cracking units to manufacture propene. In both cases economic allocation was used.

End of life allocation was done using a 50% allocation approach in which environmental credits and burdens related to the raw material production and the end of life phase are equally divided between the main product system and the new product system created by the recycled product. A sensitivity analysis on this allocation factor has been performed and is shown in Annex 1 together with the full LCA study that supports this avoided emissions study.

Downgrade factors of 0.5 and 0.8 are used in the plastics and the paper recycling, respectively, assuming that the recycled materials do not have exactly the same physical properties of virgin materials and most of the times cannot be used for the same applications. These factors vary depending on the application intended for the recycled material and they have been set at the lowest part of the spectrum to account for severe loss in quality. This is a conservative approach since it underestimates the benefits of recycling plastics.

The average shares of waste disposal for the geographic scope of this study come from [ABRELPE 2011] (disposal to sanitary landfill: 58.1%, disposal to controlled landfill: 24.2% disposal to dump: 17.7%).

5.3. Data sources and data quality

Data for the PP container product system are mainly primary data collected from Braskem operations in Brazil. However, there are no primary data for oil extraction and refining in Brazil so these data were adapted from Ecoinvent database v2. The LCA study that originated this report was concluded in 2013 and at that time, Ecoinvent v2 was the most up-to-date publicly available database.

The only process that utilized data from Ecoinvent v3 was the label offset printing, as this dataset had a more updated inventory for such process at the time the study was concluded. However, this data was inserted, through EcoSPold software, on the v2 inventory on Simapro 7.3, used on the modelling.

The full LCA report is provided for further understanding of the trade-offs involved and therefore, the original data are presented here for consistency. However, sensitivity analysis using the latest versions of EcoInvent (v3) and SimpaPro (v8.04) were conducted and there was no significant change on the results.

The Ecoinvent database is the largest LCI database in the world and also the most up to date source of public data. Table 1 shows the data sources used in this study.
Road transport in Brazil is based on the process 'transport, lorry> 32t, EURO3/RER U', considering the most recent statistical data on the types of engines in Brazilian truck fleet, which refers to 2009 [ILOS 2011]. According to this reference, in 2009 there were no EURO 4 trucks in the Brazilian fleet. Moreover, a higher load factor is assumed (70%) [Barreto 2007], which is 56.25% in Europe [Spielmann et al 2007]. The type of diesel is also adapted by choosing the conventional diesel instead of the low sulfur diesel, considering data from sulfur in diesel fuel sold in 2012 [CNT 2012].

The Brazilian energy matrix is updated based on data of domestic electricity supply by source in 2011 from the National Energy Balance [EPE 2012].

Recycling rates of 10.8% for polypropylene [Plastivida 2010], 47% for tinplate [ABEAÇO, 2010] and 13.2% for the low density polyethylene [Plastivida 2010] are assumed.

TABLE 1 - DATA SOURCES

Product System	Component	Material or process	Data Source	Reference Year
PP Container	Body	Polypropylene, at PP5 plant of Braskem/BR U mix	Braskem/ACV Brasil	2011-2012
		Blow moulding/RER U*	Ecoinvent v2.2 based on [Habersatter et al 1998] and [Boustead 1997]	1997-1998
	Lid	Polypropylene, at PP5 plant of Braskem/BR U mix	Braskem/ACV Brasil	2011-2012
		Injection moulding/RER U*	Ecoinvent v2.2 based on [Habersatter et al 1998] and [Boustead 1997]	1997-1998

Product System	Component	Material or process	Data Source	Reference Year
PP Container	Seal	Aluminium, production mix, at plant/RER U*	Ecoinvent v2.2 based on [EAA 2000]	2000
		Liquid packaging board, at plant/RER U*	Ecoinvent v2.2 based on [Habersatter et al 1998] and environmental reports of Scandinavian producers	1998-2001
		Polyethylene, HDPE, granulate, at plant/RER U*	Ecoinvent v2.2 based on [Boustead 2005]	2005
		Production of liquid packaging board containers, at plant/RER U*	Ecoinvent v2.2 based on [Habersatter et al 1998] and [Tetrapack 2001]	1998-2001
	Label	Paper, woodfree, coated, at regional storage/RER U*	Ecoinvent v2.2 based on [KCL 2002] and several CER’s of fine paper mills	2002
		Offset printing, per kg printed paper/CH U*	Ecoinvent v3 based on three average swiss companies	2007-2011
Tin Plate Container	Body	Steel, converter, low-alloyed, at plant/BR U*	Ecoinvent v2.2 based on basic oxygen furnaces in Europe and [IPCC 2001]	2001
		Hot rolling, steel/BR U*	Ecoinvent v2.2 based on [IPCC 2001]	2001
		Tin plating, pieces/BR U*	Ecoinvent v2.2 based on data from an established galvanizing company in central Europe	2001-2005
		Sheet rolling, steel/RER U*	Ecoinvent v2.2 based on [IPCC 2001]	2001
		Steel product manufacturing, average metal working/RER U*	Ecoinvent v2.2 based on eight environmental reports of companies in the engineering business	2002-2005
	Lid	Polyethylene, LDPE, granulate, at plant/RER U	Ecoinvent v2.2 based on [Boustead 2005]	2005
		Injection moulding/RER U*	Ecoinvent v2.2 based on [Habersatter et al 1998] and [Boustead 1997]	1997-1998
	Seal	Aluminium, primary, at plant/RER U*	Ecoinvent v2.2 based on [EAA 2000]	2000
		Sheet rolling, aluminium/RER U*	Ecoinvent based on [IPCC 2001]	2001
		Aluminium product manufacturing, average metal working/RER U*	Ecoinvent v2.2 based on eight environmental reports of companies in the engineering business	2002-2005
	Label	Paper, woodfree, coated, at regional storage/RER U*	Ecoinvent v2.2 based on [KCL 2002] and several CER’s of fine paper mills	2010
		Offset printing, per kg printed paper/CH U*	Ecoinvent v3 based on three average swiss companies	2007-2011
End of Life		-Dump -Controled landfill -Sanitary landfill	Adaptations made from ecoinvent v2.2 willing to represent Brazilian disposal scenarios	2008

6. Results

6.1. Avoided emissions

The detailed results are shown in Table 2 below:

TABLE 2 – THE RESULTS OF THE CASE STUDY

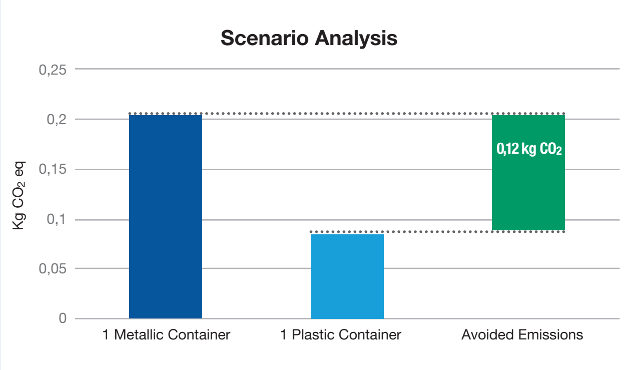
Life Cycle Stage	1 Plastic Container kCO_2/400g of chocolate powder	1 Metalic Container kCO_2/400g of chocolate powder
Raw Material	0,06	0,12
Manufacturing/Processing	0,02	0,10
Transport	2,54E-03	5,11E-03
End of Life/Disposal	3,82E-03	-0,02
Total	0,09	0,21
Avoided Emissions	0,12	

“Raw material” life cycle stage refers to manufacture of the PP resin and to the manufacturing of steel plates and zinc extraction. This stage, for the tinplate container, is dominated by the extraction of iron ore, the production of pig iron in blast furnace and the production of low alloyed steel from pig iron and iron scrap, and presents the highest emission in this products Life Cycle. The high impact is mainly related to the energy and chemicals consuming production of pig iron and steel, and to the emissions from these processes, e.g. sulfur and nitrogen oxides, carbon dioxide and monoxide, halons and CFCs to air. Ad for the PP resin, this stage is dominated by the oil extraction and the production of PP, and also presents the Global Warming impact in this product’s Life Cycle. The high impact in this category is mainly related to the consumption of crude oil to produce fossil PP and to the airborne emissions from the propene production, e.g. sulfur and nitrogen oxides, carbon dioxide and ethylene.

The “Manufacturing and Processing” life cycle stage, for the tinplate container, is dominated by the rolling and tin plating of steel to produce de body and the injection molding to produce the lid. It also includes the zinc coating and varnishing and also cutting, molding and welding, the main contributors to the large difference in GHG emissions in this stage between both product alternatives. The conversion of PP into the container body and the lid, respectively by blow molding and by injection molding, dominate this stage on the PP container life cycle. The impact in this stage is mainly related to emissions from the processing of the components (body, lid, seal and label), e.g. Halon and CFC emissions in the laminated seal production, but are also closely related to the emissions coming from the production of electricity from sugarcane bagasse in Brazil.

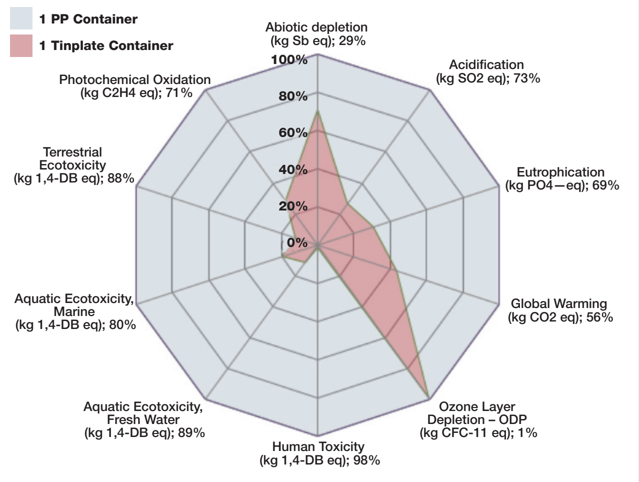
The transport stage has a minor influence on the tinplate container life cycle emissions, and the most visible results are largely due to the airborne emissions of pollutants as nitrogen oxides in the operation of lorries and the emissions of halon and CFCs from the crude oil production. Its end of life has a positive influence due to the credits coming from the high recycling rate of steel, avoiding the production of pig iron. As for the PP container, the transport stage also presents a minor influence on this product’s life cycle, and the most visible results are largely due to the airborne emissions of pollutants as nitrogen oxides in the operation of lorries. However, this alternative shows lower emissions regarding its reduced weight comparing to the tinplate containers. As for the PP containers end of life, it also shows little influence on most of the impact categories, but its role is quite significant in the Global warming category, mainly due to the disposal processes and the transport needed for this disposal, which result in emissions of e.g. nitrogen oxides and methane to air.
The GHG emissions and the Avoided figure can be seen on Figure 3.

FIGURE 3 – GRAPH OF EACH PACKAGE´S FOOTPRINT AND THE AVOIDED EMISSIONS



Considering 2010 market data, 86.95 million units of chocolate drink powder were produced. Since each PP container avoids 0.12 kgCO_2e/400g of chocolate powder packaged, the total avoided emission by the use of PP containers is 10,09 ktonCO_2e.

FIGURE 4 – FULL IMPACT ASSESSMENT GRAPH



Concerning the full impact assessment on all indicators, it can be seen on Figure 4 that the PP container has a better environmental performance in all of the categories, therefore not presenting trade-offs between the use of the PP container and the tinplate container.

7. Significance of contribution

The resins produced by the commissioner play a vital role in the value chain and make possible the reduction of GHG emissions through it, however, all the avoided emissions calculated are attributed to the complete value chain, and not only to the chemical company. Therefore, the chemical product has an Extensive contribution to the final Avoided Emissions reached, as the product is part of the key component and its properties and functions are essential for enabling the GHG emission avoiding effect of the solution.

8. Review of results

The results have been reviewed by Brazilian LCA expert and by the original ICCA task-force responsible for the avoided emissions guidelines. The critical reviewer was part of ACV Brasil's team but did not take any part in the study which was conducted by Felipe Motta and Tiago Barreto. All comments have been incorporated to the text of the full LCA study in annex.

9. Study limitations and future recommendations

Lack of consistent and up to date data for LCA studies in Brazil is a major obstacle to the advancement of Life Cycle Management in Brazil. This lack of data has been partially dealt with the use and adaptation of international databases, namely Ecoinvent v2.

Data coming from the Ecoinvent database, despite with some adjustments for Brazilian circumstances, have limited quality and can be improved in future assessments. Furthermore, for processes without a direct correspondence with the database, similar processes were used, such as for the processing of tinplate containers from rolled steel. Here also more accurate data can be added in future studies.

The differences in representativeness of the data used for the PP alternative (based on primary data and databases) and the tinplate alternative (based on databases adapted to Brazilian conditions) represent a limitation of the study. Nevertheless, the datasets used in this study belong to the foremost database in the world and utmost care to adjust the datasets to the Brazilian conditions has been taken. Therefore both the commissioner and the executors of the study feel confident they represent the average market conditions in Brazil.

10. Conclusions

The results of this LCA study provide reasons to prefer the PP container over the established tinplate containers when choosing a packaging solution for chocolate drink powder on the Brazilian market. For the all of the regarded environmental indicators, the PP container appears as more favorable than the established containers. The reduction in GHG emissions by the use of rigid PP containers instead of tinplate containers is estimated at 56,36%.

Furthermore, an increase in the recycling rates is beneficial to all the packaging systems, with exception to the Terrestrial Eutrophication category. From this finding, the recommendation can be derived to aim at reducing the final disposal rate – and thus to increase the amount of materials that are recycled. This would also be in line with requirements of the National Policy on Solid Waste [PNRS 2010], which establishes the following order of priority: no generation, reduction, reuse, recycling, solid waste treatment and environmentally suitable disposal of waste.

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Case 3 Feed additives - DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan in broiler and pig production

Evonik

COMMISSIONER AND PERFORMER OF THE STUDY

The study has been commissioned by the Evonik Business Unit Health & Nutrition, was conducted by the Evonik Life Cycle Management Group and reviewed by the TÜV Rheinland LGA Product GmbH as an independent third party. The primary data for the study represents the situation in 2008. A new study updating these findings has been finalised by a critical review according to ISO 14044:2006 in March 2015.

1. Purpose of the study

This study assesses the reduction potential on environmental impacts to global warming, eutrophication and acidification of the use of the 4 first limiting amino acids (DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan) in typical conventional broiler and pig meat production, based on current data from practical production. The study intends to be a comparative life cycle assessment in line with the requirements defined under ISO 14040/44. As the study will be published, it will be accompanied by an independent critical review. The target groups are predominantly representatives of environmental movements and of agriculture.

This study has been conducted to provide a case study on “Amino acids in animal feed” in alignment with the requirements of the document “Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies,” developed by ICCA and the Chemical Sector Group of the WBCSD (http://www.icca-chem.org/ICCADocs/E%20CC%20LG%20guidance_FINAL_07-10-2013.pdf).

A former version of the study has been part of the following document:
“Innovations for Greenhouse Gas Reductions, A life cycle quantification of carbon abatement solutions enabled by the chemical industry”, ICCA (2009).

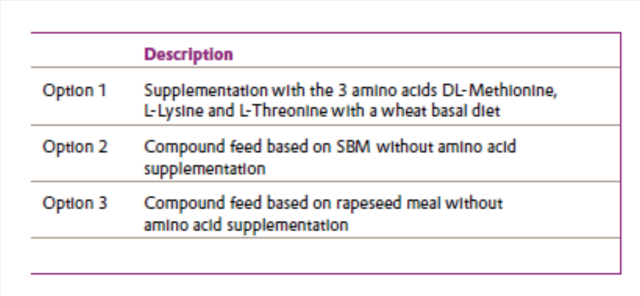
2. Solutions to compare

2.1. Description of the solutions to compare

Three options were compared:
Four amino acids: Supplementation of a defined premix consisting of the amino acids DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan
Soy bean meal (SBM): Supply of the respective amounts of amino acids by increasing the content of basic feed ingredients high in amino acids, e. g. oilseeds
Rapesweed: A second unsupplemented option covers the European industrial practice on the use of locally produced rapeseed meal instead of imported soybean

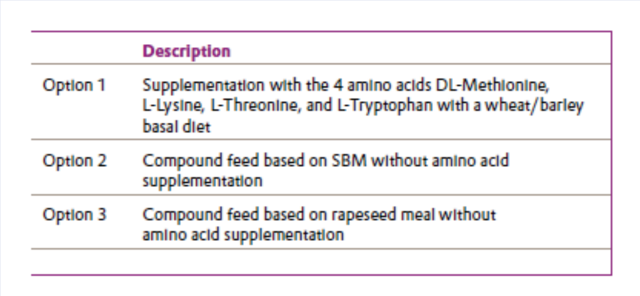
All three options ensure functional equivalence since they are offering the same nutritional value to the animals meal.

FIGURE 1 - ALTERNATIVE OPTIONS FOR BROILER FEEDING



	Description
Option 1	Supplementation with the 3 amino acids DL-Methionine, L-Lysine and L-Threonine with a wheat basal diet
Option 2	Compound feed based on SBM without amino acid supplementation
Option 3	Compound feed based on rapeseed meal without amino acid supplementation

FIGURE 2 - ALTERNATIVE OPTIONS FOR SWINE FEEDING



	Description
Option 1	Supplementation with the 4 amino acids DL-Methionine, L-Lysine, L-Threonine, and L-Tryptophan with a wheat/barley basal diet
Option 2	Compound feed based on SBM without amino acid supplementation
Option 3	Compound feed based on rapeseed meal without amino acid supplementation

2.2. Level in the Value Chain

This study focuses on the performance of amino acids, produced by chemical industry and applied in animal nutrition. Thus, the focus of this study is at the chemical product level.

2.3. Definition of the boundaries of the market and the application

Animal feed is specifically formulated to meet the physiological nutrition needs of animals, particularly the necessary shares of essential amino acids. Lack of certain amino acids in animal feed can be compensated either by adding a higher percentage of protein-rich feed components such as oil seed, or by fortifying the feed with essential amino acids produced by Evonik for this purpose.

The study compares in general three options for livestock production to cover the nutritional demand of the target species. One is the addition of supplemental amino acids to compound feed for pigs and poultry, the others are comparable compound feed with increased amounts of oilseeds such like soybean meal or rapeseed meal.

In 2013 the overall compound feed market for all species was published at 962,780 Kmt. Provided a proper application of DL-Methionine, supplemented option 1 reflects 327,345 Kmt (34 %) against 635,435 Kmt (66 %) non supplemented feed in option 2, for Biolys (L-Lysine) option 1 reflects 394,739 Kmt (41 %) against 568,041 (59 %) non supplemented feed in option 2 and finally for Threonine option 1 reflects 12,516 Kmt (1%) against 950,264 Kmt (99 %) non supplemented feed in option 2. The worldwide market volume of compound feed is dominated by broiler and pig production, other animal species play a less important role. Also the use of supplemental amino acids in compound feed production is the most used technology in pig and broiler production. Therefore the above set system boundaries for the feed market seem to be the most conclusive one.

Supplementing animal feed with essential amino acids can save significant amounts of feed raw materials, resulting in minimized use and cultivation of arable land for crop production and thus, fewer CO_2eq emissions due to avoided land use change emissions during soy bean production in Brazil and Argentina. Furthermore, feed supplementation with these essential amino acids reduces both nitrogen and greenhouse gas emissions resulting from feeding (less N_2O emissions from manure storage and from application to the field). Moreover, greenhouse gas emissions from transportation of soy bean from South America to Germany by ship and road transport decrease.

3. Functional unit and reference flow

3.1. Functional unit

Methionine, lysine, threonine and tryptophan are the four first limiting essential amino acids in animal production. Methionine as the first limiting amino acid in typical compound feed for poultry has a particular importance. Lysine is the first limiting amino acid in swine nutrition and plays a particularly important role here. Threonine and also Tryptophan are further limiting amino acids for both species. It is of utmost importance that the respective daily amino acid requirement for each species is fully covered in order to guarantee a healthy and well balanced nutrition. Otherwise a distinct drop in performance and a detrimental effect on the animal's health will occur. Alternatively, the supply of the respective amounts of amino acids has to be ensured by increasing the content of basic feed ingredients high in amino acids, e. g. oilseeds (quality requirement "functionality"). Eight to ten so-called essential amino acids cannot be produced by humans or animals itself. They must be consumed regularly with the food since amino acids can be poorly stored in the body if the diet is not well balanced. The body requires a well-balanced amino acid supply daily in order to remain healthy and effective. A deficiency of essential amino acids will cause impaired protein synthesis and life-threatening deficiency symptoms in humans or animals. In commercial agricultural animal production amino acids are important supplements to proteins from agriculturally produced feed ingredients. They provide the option to reduce the protein content in animal feed.

The functional unit was defined as 1 kg of an amino acid mix consisting of DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan which is supplemented to the feed or the equivalent amount of amino acids provided by feed raw materials rich in these amino acids such as oilseed meals.

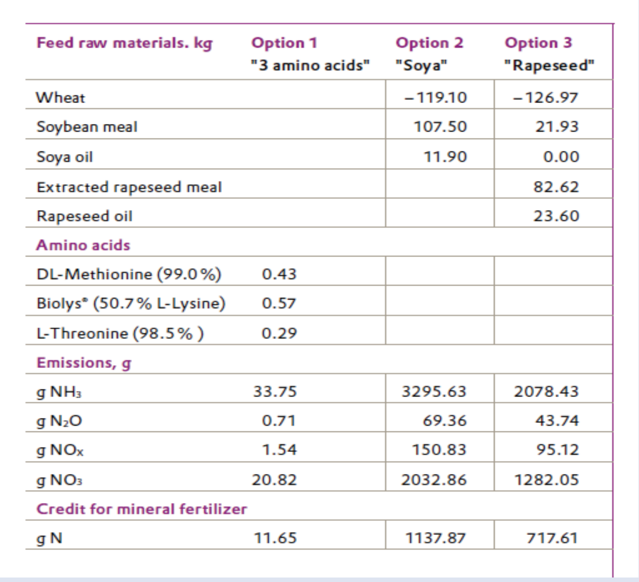
The quality criteria "functionality" has been taken into consideration. The supply of the respective amounts of amino acids has to be ensured either by an amino acid mix consisting of DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan which is supplemented to the feed or by increasing the content of basic feed ingredients high in amino acids, e. g. oilseeds. This requirement results in a functional unit of 1 kg amino acids either provided by supplementation or by increasing the content of basic feed ingredients, e. g. oilseeds.

Animal feed is determined for immediate consumption and thus does not have a "service life".
The primary data for the production of the four amino acids represent the situation in 2008. The modeling of the life cycle assessment was done with the GaBi software[7] of PE International. The data set for the following sites were used: Belgium for DL-Methionine, United States for L-Lysine, Hungary for L-Threonine, Slovakia for L-Tryptophan, and Germany for the other life cycle phases (see chapter 6.1 for additional information on time and geographic reference).

3.2. Reference flow

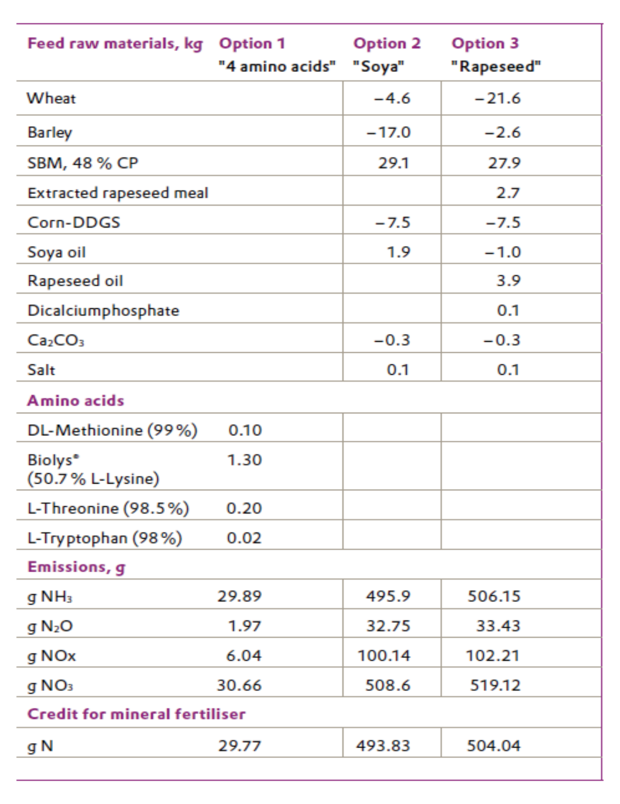
The functional unit was defined as 1 kg of an amino acid mix consisting of DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan which is supplemented to the feed or the equivalent amount of amino acids provided by feed raw materials rich in these amino acids such as oilseed meals. The reference flows were calculated by generating net differences between the feeding options. The reference flows for broiler and swine feeding are each indicated in the following Tables.

FIGURE 3 - LIFE CYCLE INVENTORY OF BROILER PRODUCTION



Feed raw materials. kg	Option 1 "3 amino acids"	Option 2 "Soya"	Option 3 "Rapeseed"
Wheat		−119.10	−126.97
Soybean meal		107.50	21.93
Soya oil		11.90	0.00
Extracted rapeseed meal			82.62
Rapeseed oil			23.60
Amino acids			
DL-Methionine (99.0 %)	0.43		
Biolys® (50.7 % L-Lysine)	0.57		
L-Threonine (98.5 %)	0.29		
Emissions, g			
g NH_3	33.75	3295.63	2078.43
g N_2O	0.71	69.36	43.74
g NO_x	1.54	150.83	95.12
g NO_3	20.82	2032.86	1282.05
Credit for mineral fertilizer			
g N	11.65	1137.87	717.61

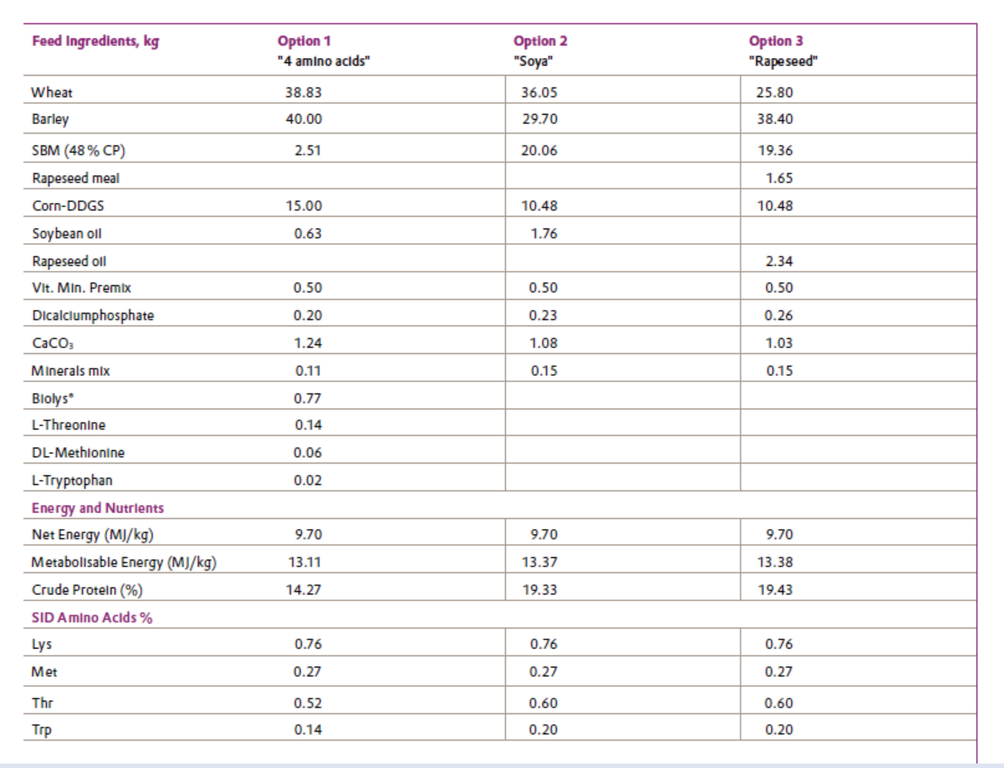
FIGURE 4 - LIFE CYCLE INVENTORY OF SWINE PRODUCTION



Feed raw materials, kg	Option 1 "4 amino acids"	Option 2 "Soya"	Option 3 "Rapeseed"
Wheat		−4.6	−21.6
Barley		−17.0	−2.6
SBM, 48 % CP		29.1	27.9
Extracted rapeseed meal			2.7
Corn-DDGS		−7.5	−7.5
Soya oil		1.9	−1.0
Rapeseed oil			3.9
Dicalciumphosphate			0.1
Ca_2CO_3		−0.3	−0.3
Salt		0.1	0.1
Amino acids			
DL-Methionine (99 %)	0.10		
Biolys® (50.7 % L-Lysine)	1.30		
L-Threonine (98.5 %)	0.20		
L-Tryptophan (98 %)	0.02		
Emissions, g			
g NH_3	29.89	495.9	506.15
g N_2O	1.97	32.75	33.43
g NOx	6.04	100.14	102.21
g NO_3	30.66	508.6	519.12
Credit for mineral fertiliser			
g N	29.77	493.83	504.04

TABLE 1 - WEIGHTED MEANS OF NUTRITIONALLY EQUIVALENT COMPOUND FEEDS FOR SWINE

(10 % GROWER FEED PHASE 1, 30 % GROWER FEED PHASE 2, 60 % FINISHER FEED PHASE)



Feed Ingredients, kg	Option 1 "4 amino acids"	Option 2 "Soya"	Option 3 "Rapeseed"
Wheat	38.83	36.05	25.80
Barley	40.00	29.70	38.40
SBM (48 % CP)	2.51	20.06	19.36
Rapeseed meal			1.65
Corn-DDGS	15.00	10.48	10.48
Soybean oil	0.63	1.76	
Rapeseed oil			2.34
Vit. Min. Premix	0.50	0.50	0.50
Dicalciumphosphate	0.20	0.23	0.26
$CaCO_3$	1.24	1.08	1.03
Minerals mix	0.11	0.15	0.15
Biolys®	0.77		
L-Threonine	0.14		
DL-Methionine	0.06		
L-Tryptophan	0.02		
Energy and Nutrients			
Net Energy (MJ/kg)	9.70	9.70	9.70
Metabolisable Energy (MJ/kg)	13.11	13.37	13.38
Crude Protein (%)	14.27	19.33	19.43
SID Amino Acids %			
Lys	0.76	0.76	0.76
Met	0.27	0.27	0.27
Thr	0.52	0.60	0.60
Trp	0.14	0.20	0.20

TABLE 2 - CALCULATED FEED MIXES FOR BROILER PRODUCTION

Feed ingredients	**Option 1** **„4 amino acids“**	**Option 2** **„Soya“**	**Option 3** **„Rapeseed“**
Wheat (g/kg feed)	672	453	438
Soy bean meal (g/kg feed)	230	429	270
Soy bean oil (g/kg feed)	46	68	46
Rapeseed meal (g/kg feed)			153
Rapeseed oil (g/kg feed)			43
Premix (g/kg feed)	50	50	50
Amino acids			
DL methionine (99,0 % DL methionine) (g/kg feed)	0,80		
Biolys® (50,7 % L lysine) (g/kg feed)	1,06		
L-Threonine (98,5 % L-threonine) (g/kg feed)	0,53		
Energy and Nutrients			
Metabolisable Energy (MJ/kg feed)	12,7	12,7	12,7
Crude Protein (g/kg feed)	192	257	232
Methionine, digestible (g/kg feed)	3,1	3,1	3,1
Lysine, digestible (g/kg feed)	8,2	12,1	10,3
Threonine, digestible (g/kg feed)	6,1	8,1	7,4

4. Boundary setting

The system boundaries for all scenarios equivalent to the 3 compound feed options follow the principle „from cradle to farm-gate“, i. e. they start from providing the raw materials used for production of the supplemental amino acids, the cultivation of the basic feed ingredients, the manufacturing of the mineral fertilizer for agricultural production, the harvest and processing of the agricultural raw materials as well as all transport of all feed ingredients, raw materials and intermediates including all emissions relating to animal production and distribution of manure. Figure 2-7 provides insight into all levels of the life cycle analysis. The compound feed processing was not considered within the system boundaries, because the authors of the study considered the same ecological burden of each type of compound feed through the feed mill processing. In the final comparison, this would be neutralized anyway.

FIGURE 5 - SYSTEM BOUNDARIES FOR THE OPTIONS ANALYSED IN BROILER AND SWINE FEEDING

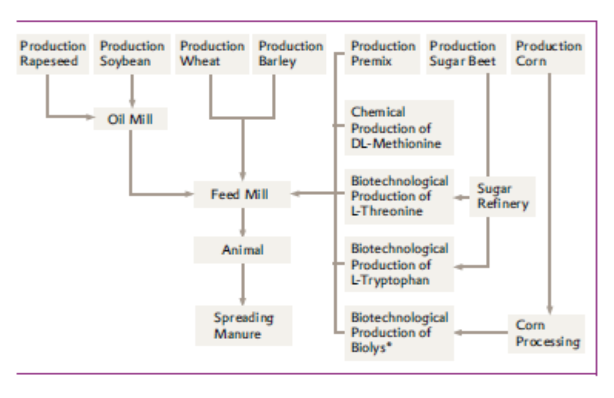
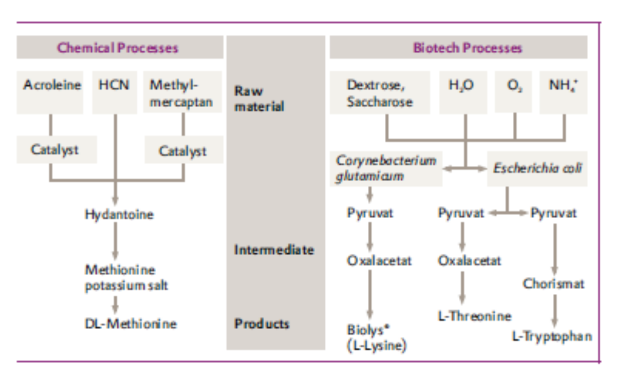


FIGURE 6 - RELEVANT MATERIAL FLOW AND RAW MATERIALS FOR THE RESPECTIVE TYPE OF MANUFACTURING



Compound Feed Production

Animal feed is usually processed in a feed mill before being fed to the animal. This is predominantly done to ideally mix the feed ingredients. Feed milling can take place on the farms or more often at special feed mills which provide the farms with ready mixed feed. For this study the compound feed processing was not considered within the system boundaries, because the authors of the study considered the same ecological burden of each type of compound feed through the feed mill processing. In the final comparison, this would be neutralized anyway.

Manure Management

Manure management includes manure storage and manure field application. The excretions of animals can be stored under the animal either as liquid slurry or as litter and is pumped to external tanks or removed manually with wheel loaders or tractors. The excretions from animals lead to nitrogen and carbon based emissions to air (CH_4, N_2O, N_2 and NH_3) and – depending on the way of storage – potentially NO_3- and PO_4- emissions to water. The magnitude of these emissions depends among other things on the husbandry and storage technology, on the development stage, manure composition and the climate conditions. The manure composition is directly dependent on animal performance (feed conversion ratio) and feed composition (concentration of crude protein and total phosphorus (Rigolot et al. 2010). Subsequent to the housing and temporal storage the manure has to be stored until application on agricultural land. Manure may be stored for several days to several months, mainly depending on the weather, legal regulations and crop nutrient demand. There are several different storage technologies available. Manure application to agricultural land is on most farms an indispensable part of the manure management system. It closes the internal nutrient cycling system of the farm, when sufficient land is available on the animal production farm. For this process step several technologies (broad cast, injection etc.) are available and associated with various emission profiles depending also on climatic conditions and regional quality of the soil. Besides emissions manure generates a benefit to the system by providing essential nutrients for cash- and feed crops. Both, emissions and credits can have a significant impact on the LCA.

5. Calculation methodology and data

5.1. Methods and formulas used

The current study focuses on a few, but important environmental categories for the specific application of amino acids in animal nutrition:

- Global warming potential (GWP100) [kg CO_2eq according to IPCC 2007]
- Acidification potential (AP) [kg SO_2eq]
- Eutrophication potential (EP) [kg PO_4eq]
- Primary energy demand (PED) [MJ]
- Consumption of resources [kg Crude oil-eq]

The environmental impact categories GWP, AP and EP have been evaluated using the CML-methodology[1] with updated characterization factors of August 2007 (IPCC 2007). In quantification of the global warming potential the inclusion of land use change (LUC) for soya production in South America has a very strong influence on the results. That's why a sensitivity analysis has been conducted. It was assumed for the evaluation that about 3.2 % [5, p. 130] of soya in South America is grown on land that originally was rain forest. No land use change was considered for the 15 % of soy bean meal (SBM) imported from the US. The primary energy demand is calculated based on the lower heat value of all energy sources used in the model including the energy used for intermediates. All kinds of energy are considered including fossil and renewable energy. The consumption of resources was calculated using the methodology of the UBA (UBA 1995, Ökobilanzen für Getränkeverpackungen, Teil A: Methode zur Berechnung und Bewertung von Ökobilanzen für Verpackungen, Berlin). This is restricted on the consumption of fossil energies such as crude oil, hard coal, soft coal and natural gas.

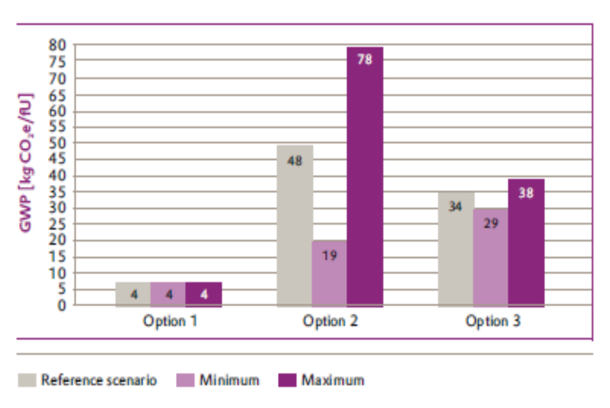
Broiler production - Sensitivity analysis of "land use change soya"

In contrast to the earlier IFEU studies the aspect of land use change was evaluated additionally in the current study. This topic has gained increasing importance in the discussion on renewable raw materials for biofuels. This was the reason why this aspect was newly integrated in the life cycle assessment methodology. Additionally there are reliable scientific data on LUC available.

The base scenario assumed was a reference situation for soya production in South America including a certain extent of land use change. In the sensitivity analysis a varying percentage of soya grown in the respective regions is studied. Indirect land use change was not considered as the methodology and mode of calculation is still subject of scientific discussions. In the sensitivity analysis "land use change soya" the portion of soya from land which had undergone land use change (see Table 5 – 1) was either doubled (maximum) or cut in half (minimum). In modeling this affects the two data sets "soybean meal" and "soybean oil". The import split i.e. the portion of SBM from the US, Brazil, and Argentina remained unchanged.

The land use change primarily affects emissions relevant for the climate factors which then has an impact on GWP (see Figure 5 – 1). The major effect is caused by the degradation of biomass stored in the soil releasing the CO_2 fixed in the soil. Additional information can be found in the documentation of PE Int. and the sources cited in there[12].

FIGURE 7 - GLOBAL WARMING POTENTIAL [CML 2001] FROM BROILER PRODUCTION – SENSITIVITY ANALYSIS FOR "LAND USE CHANGE SOYA"



The range assumed for soya does not have an impact on the scenario “amino acids” as no SBM is included in the functional unit for this option. The GWP for option 1 remains unchanged accordingly at a level of 4 kg CO_2eq/fU. Cutting in half the soya from land based on direct land use change in South America in option 2 reduces GWP by approx. 30 kg CO_2eq to a level of 19 kg CO_2eq/fU while doubling brings GWP to a level as high as 78 kg CO_2eq/fU. The corresponding values for option 3 vary between 29 kg and 38 kg CO_2eq/fU.

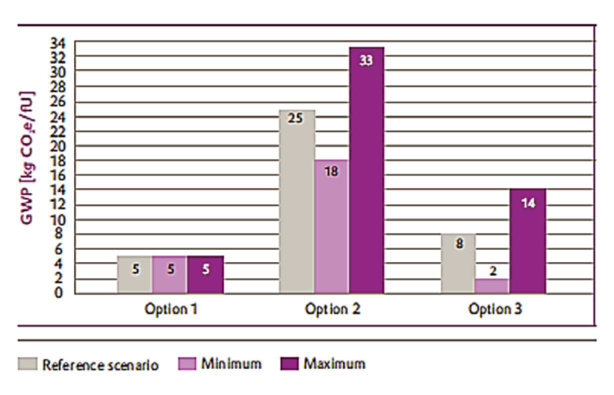
Swine production - Sensitivity analysis “land use change soya”

The approach for the sensitivity analysis was explained in chapter 5.1.1 for broiler production. This same approach and the variation of parameters provided in Table 5 – 1 were also applied for swine production.

The land use change primarily affects emissions relevant for the climate factors which then has an impact on GWP (see Figure 5 – 5). The major effect is caused by the degradation of biomass stored in the soil releasing the CO_2 fixed in the soil. Additional information can be found in the documentation of PE Int. and the sources cited in there.

The range assumed for soya does not have an impact on the scenario of option 1 as no SBM is included in the functional unit for this option. The GWP for option 1 remains unchanged accordingly at a level of 5 kg CO_2eq/fU. Cutting in half the soya from land based on direct land use change in South America in option 2 reduces GWP by approx. 7 kg CO_2eq to a level of 18 kg CO_2eq/fU while doubling brings GWP to a level as high as 33 kg CO_2eq/fU. The corresponding values for option 3 vary between 2 kg and 14 kg CO_2eq/FU.

FIGURE 8 - GLOBAL WARMING POTENTIAL [CML 2001] FOR SWINE PRODUCTION – SENSITIVITY ANALYSIS “LAND USE CHANGE SOYA”



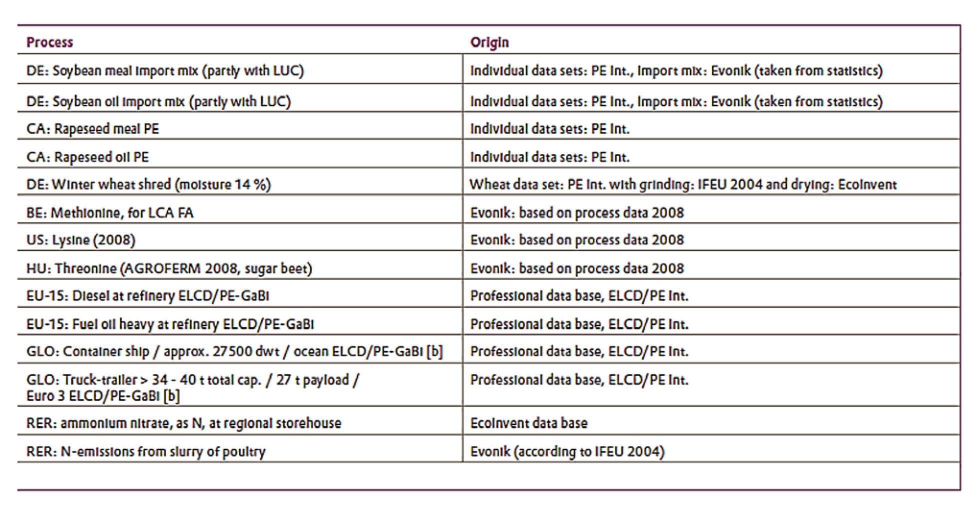
5.2. Allocation

No allocation was performed for amino acid and feed production. Specific individual agricultural raw material data sets by PE International (e.g. DDGS, soybean meal and oil, rapeseed meal and oil) are based on allocation methods which are described in the respective data set documentation (see also following Tables).

5.3. Data sources and data quality

The primary data for the production of the four amino acids represent the situation in 2008. They were provided by the respective production unit. The secondary data for the background systems such as energy supply, agricultural raw materials and minerals, transport and disposal originate from the database of GaBi[7] from PE International. Some of the processes- in contrast – were estimated on the basis of literature data. EcoInvent-Data[6] were used for those few cases for which no set of GaBi data was available.

TABLE 3 - ORIGIN OF PROCESS DATA FOR BROILER PRODUCTION



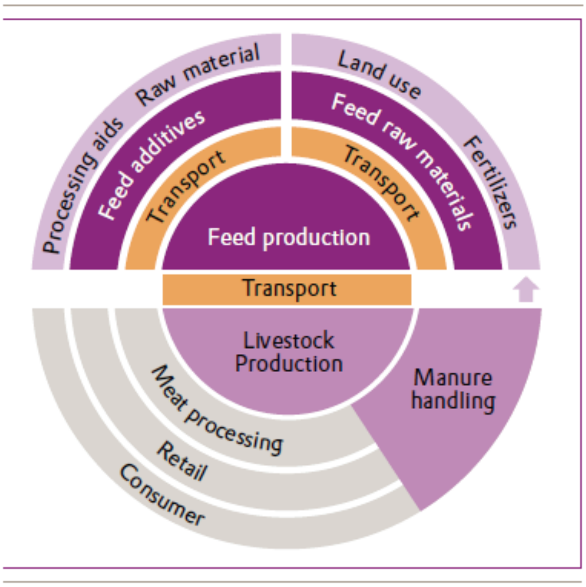
Process	Origin
DE: Soybean meal import mix (partly with LUC)	Individual data sets: PE Int., Import mix: Evonik (taken from statistics)
DE: Soybean oil import mix (partly with LUC)	Individual data sets: PE Int., Import mix: Evonik (taken from statistics)
CA: Rapeseed meal PE	Individual data sets: PE Int.
CA: Rapeseed oil PE	Individual data sets: PE Int.
DE: Winter wheat shred (moisture 14 %)	Wheat data set: PE Int. with grinding: IFEU 2004 and drying: EcoInvent
BE: Methionine, for LCA FA	Evonik: based on process data 2008
US: Lysine (2008)	Evonik: based on process data 2008
HU: Threonine (AGROFERM 2008, sugar beet)	Evonik: based on process data 2008
EU-15: Diesel at refinery ELCD/PE-GaBi	Professional data base, ELCD/PE Int.
EU-15: Fuel oil heavy at refinery ELCD/PE-GaBi	Professional data base, ELCD/PE Int.
GLO: Container ship / approx. 27500 dwt / ocean ELCD/PE-GaBi [b]	Professional data base, ELCD/PE Int.
GLO: Truck-trailer > 34 - 40 t total cap. / 27 t payload / Euro 3 ELCD/PE-GaBi [b]	Professional data base, ELCD/PE Int.
RER: ammonium nitrate, as N, at regional storehouse	EcoInvent data base
RER: N-emissions from slurry of poultry	Evonik (according to IFEU 2004)

TABLE 4 - ORIGIN OF PROCESS DATA FOR SWINE PRODUCTION

Process	Origin
DE: Soybean meal import mix (partly with LUC)	Individual data sets: PE int., Import mix: Evonik (taken from statistics)
DE: Soybean oil import mix (partly with LUC)	Individual data sets: PE int., Import mix: Evonik (taken from statistics)
CA: Rapeseed meal PE	Individual data sets: PE int.
CA: Rapeseed oil PE	Individual data sets: PE int.
DE: Winter wheat shred (moisture 14%)	Wheat data set: PE Int. incl. grinding: IFEU 2004 and drying: EcoInvent
DE: Summer barley shred (moisture 14%)	Wheat data set: PE Int. incl. grinding: IFEU 2004 and drying: EcoInvent
US: DDGS (Allocation-Model, DDGS with burden) PE	Individual data sets: PE int.
DE: Limestone flour (0.1 mm) PE	Professional data base, PE Int.
DE: Sodium chloride (rock salt) PE	Professional data base, ELCD/PE Int.
DE: Dicalcium phosphate (estimation) PE	Individual data sets: PE int.
BE: Methlonine, for LCA FA	Evonik: based on process data 2008
US: Lysine (2008)	Evonik: based on process data 2008
HU: Threonine (AGROFERM 2008, sugar beet)	Evonik: based on process data 2008
SK: Tryptophan process (FERMA S 2008, sugar beet)	Evonik: based on process data 2009
EU-15: Diesel at refinery ELCD/PE-GaBi	Professional data base, ELCD/PE Int.
EU-15: Fuel oil heavy at refinery ELCD/PE-GaBi	Professional data base, ELCD/PE Int.
GLO: Container ship / approx. 27500 dwt / ocean ELCD /PE-GaBi (b)	Professional data base, ELCD/PE Int.
GLO: Truck-trailer > 34 – 40 t total cap / 27 t payload / Euro 3 ELCD / PE-GaBi (b)	Professional data base, ELCD/PE Int.
RER: ammonium nitrate, as N, at regional storehouse	EcoInvent data base
RER: N-emissions from slurry of poultry	Evonik (according to IFEU 2004)

The following figure indicates the system boundaries and the availability of primary data for modeling the individual scenarios for the functional unit (FU). The fields with grey background are not within the share of influence of Evonik. There is a need to use data from secondary sources for this. The darker colored segments highlight a close proximity of factors to the business of the sponsor. The darker the color the larger the influence. More primary data are available here.

FIGURE 9 - SYSTEM BOUNDARIES - AVAILABILITY OF PRIMARY DATA FOR MODELING



6. Results

6.1. Avoided emissions

The avoided emissions are indicated in the below Table.

Broiler production

FIGURE 10 - GLOBAL WARMING POTENTIAL GWP100 [CML 2001] OF BROILER PRODUCTION

Avoided Emissions	Avoided Emissions (Option 2 – Option 1)	Avoided Emissions (Option 3 – Option 1)
Global warming potential GWP100 [1] in kg CO_2eq/functional unit	44	30

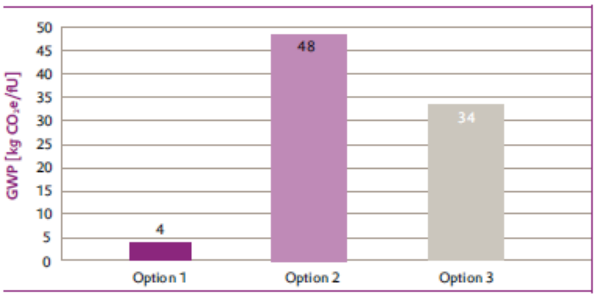
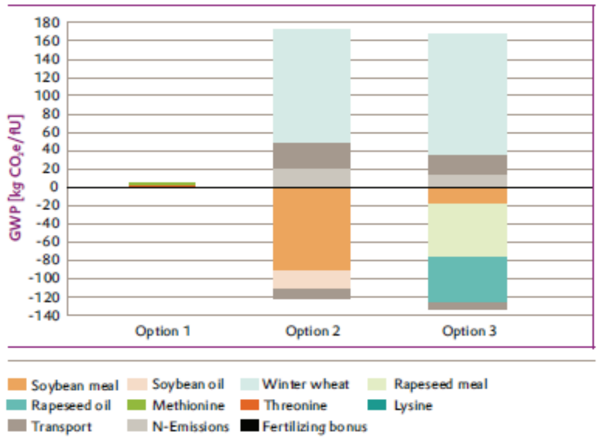


FIGURE 11 - GLOBAL WARMING POTENTIAL GWP100 [CML 2001] OF BROILER PRODUCTION BROKEN DOWN BY CONTRIBUTIONS OF INDIVIDUAL FACTORS

Emissions	Option 1 (Evonik's solution)	Option 2 (Solution to compare)	Option 3 (Solution to compare)
Global warming potential GWP100 [1] in kg CO_2eq/functional unit	4	48	34



Calculating the reference flows by generating net differences between the feeding options generally leads to negative credits for avoided ingredients and positive contributions by those ingredients included in the individual diet.

The key parameters for the greenhouse gas reduction compared to option 2 are winter wheat and soybean meal. The supplemented feed mix in option 1 uses more winter wheat compared to option 2 and therefore results in a lower GWP due to a higher uptake of CO_2 during crop growth. In contrast, the supplemented feed mix in option 1 uses less soybean meal compared to option 2 and therefore results in a higher GWP due to less uptake of CO_2 during soybean growth. Both effects lead to a lower GWP of the supplemented feed mix in option 1 in total.

Swine production

FIGURE 12 - GLOBAL WARMING POTENTIAL GWP100 [CML 2001] OF SWINE PRODUCTION

Avoided Emissions	Avoided Emissions (Option 2 – Option 1)	Avoided Emissions (Option 3 – Option 1)
Global warming potential GWP100 [1] in kg CO_2eq/functional unit	20	3

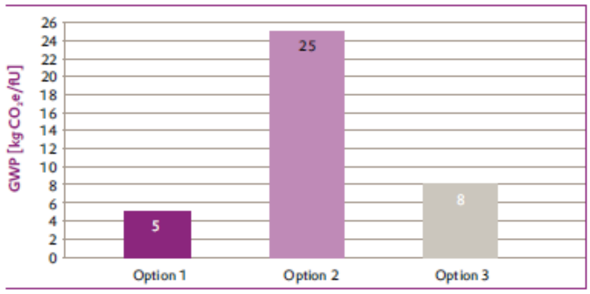
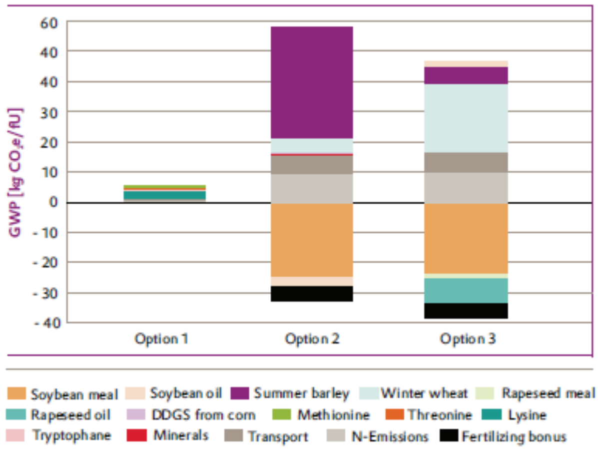


FIGURE 13 - GLOBAL WARMING POTENTIAL GWP100 [CML 2001] OF SWINE PRODUCTION BROKEN DOWN BY INDIVIDUAL CONTRIBUTIONS OF FACTORS

Emissions	Option 1 (Evonik's solution)	Option 2 (Solution to compare)	Option 3 (Solution to compare)
Global warming potential GWP100 [1] in kg CO_2eq/functional unit	5	25	8



Calculating the reference flows by generating net differences between the feeding options generally leads to negative credits for avoided ingredients and positive contributions by those ingredients included in the individual diet.

The key parameters for the greenhouse gas reduction compared to option 2 are summer barley and soybean meal. The supplemented feed mix in option 1 uses more summer barley compared to option 2 and therefore results in a lower GWP due to a higher uptake of CO_2 during crop growth. In contrast, the supplemented feed mix in option 1 uses less soybean meal compared to option 2 and therefore results in a higher GWP due to less uptake of CO_2 during soybean growth. Both effects lead to a lower GWP of the supplemented feed mix in option 1 in total.

6.2. Scenario analysis

No scenario analysis on future developments has been performed in this study.

7. Significance of contribution

The credit for the avoided emissions belongs to the whole value chain. Amino acids produced by Evonik have a fundamental contribution to the avoided greenhouse gas emissions.

8. Review of results

The study has been reviewed by the German TÜV Rheinland in 2010 and recertified in 2012. Further information on the review can be found at http://www.tuv.com under the certificate number “0000027153”.

9. Study limitations and future recommendations

The current study focuses on a few, but important environmental categories for the specific application of amino acids in animal nutrition:

- Global warming potential (GWP100) [kg CO_2- equiv.]
- Acidification potential (AP) [kg SO_2- equiv.]
- Eutrophication potential (EP) [kg PO_4-equiv.]
- Primary energy demand (PED) [MJ]
- Consumption of resources [kg Crude oil-equiv.]

The functional unit has been chosen in the respective way, because the influence of the amino acids and not the influence of animal keeping and growth should be evaluated.

The study shows the environmental impacts for certain feed options, but neither evaluates the livestock keeping nor the manure storage and spreading. It is therefore not possible to derive recommendations for best practice livestock keeping on the farm.

10. Conclusions

The current study was able to identify a further improvement for the major environmental categories. One of the reasons is the further development of the production technology since 2004 in chemical synthesis and in biotechnological fermentation. On the other hand the modeling process was further developed and more transparent data sets are available from environmental data bases. Additionally the study outlines also that the advanced inclusion level of crystalline amino acids to animal diets further leads to environmental savings.

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12. Appendices

Report of the main results other than GHG emissions

Broiler production

FIGURE 14 - ACIDIFICATION POTENTIAL AP [CML 2001] OF BROILER PRODUCTION

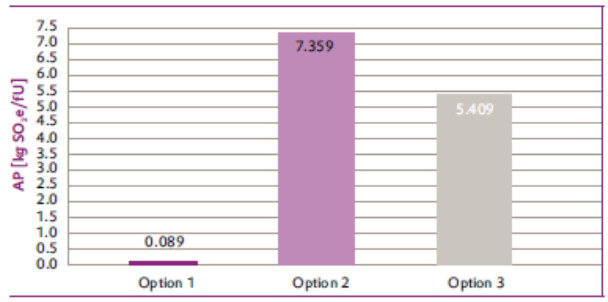


FIGURE 15 - EUTROPHICATION POTENTIAL EP [CML 2001] OF BROILER PRODUCTION

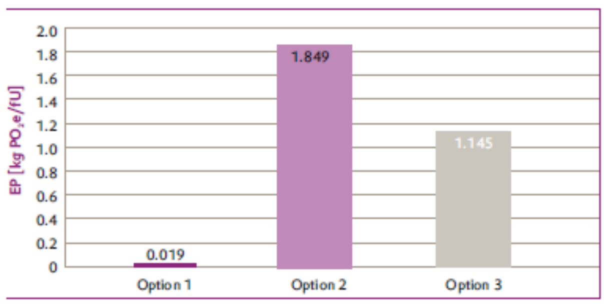


FIGURE 16 - PRIMARY ENERGY DEMAND (PED) OF BROILER PRODUCTION

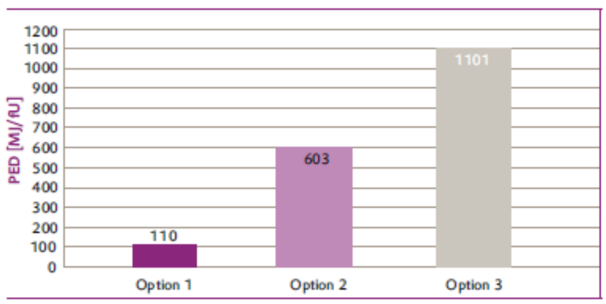
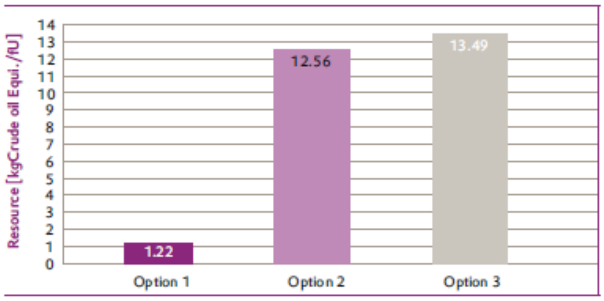


FIGURE 17 - RESOURCE CONSUMPTION OF BROILER PRODUCTION



Emissions	Option 1 (Evonik's solution)	Option 2 (Solution to compare)	Option 3 (Solution to compare)
Acidification potential AP [1] in kg SO$_2$e/functional unit	0.089	7.359	5.409
Eutrophication potential EP [1] in PO$_4$e/functional unit	0.019	1.849	1.145
Primary energy demand PED in MJ/functional unit	110	603	1101
Resource consumption in kg crude oil equi./functional unit	1.22	12.56	13.49

Swine production

FIGURE 18 - ACIDIFICATION POTENTIAL AP [CML 2001] OF SWINE PRODUCTION

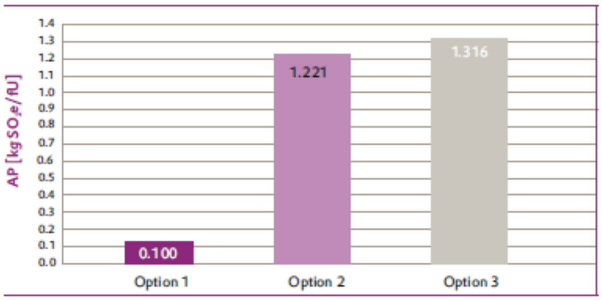


FIGURE 19 - EUTROPHICATION POTENTIAL EP [CML 2001] OF SWINE PRODUCTION

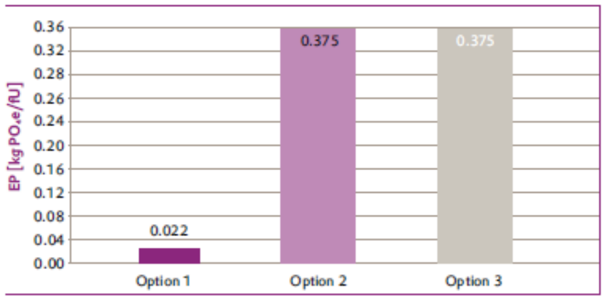


FIGURE 20 - PRIMARY ENERGY DEMAND (PED) OF SWINE PRODUCTION

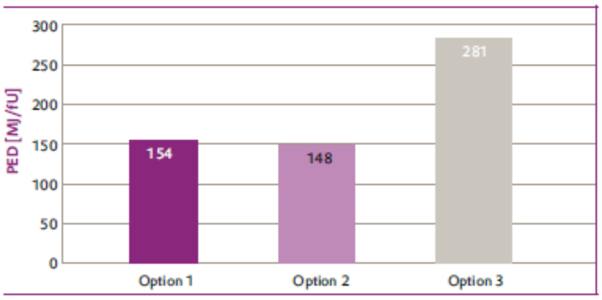
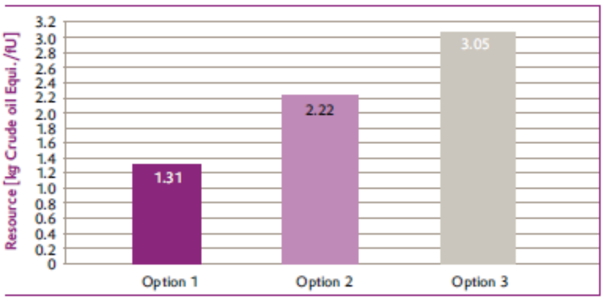


FIGURE 21 - RESOURCE CONSUMPTION OF SWINE PRODUCTION



Emissions	Option 1 (Evonik's solution)	Option 2 (Solution to compare)	Option 3 (Solution to compare)
Acidification potential AP [1] in kg SO_2e/functional unit	0.1	1.221	1.316
Eutrophication potential EP [1] in PO_4e/functional unit	0.022	0.375	0.375
Primary energy demand PED in MJ/functional unit	154	148	281
Resource consumption in kg crude oil equi./functional unit	1.31	2.22	3.05

6.1. Avoided emissions

The credit for the avoided emissions belongs to the whole value chain. The avoided emissions are indicated in the below Tables.

Broiler production

Avoided Emissions	Avoided Emissions (Option 2 – Option 1)	Avoided Emissions (Option 3 – Option 1)
Acidification potential AP [1] in kg SO_2e/functional unit	7.27	5.32
Eutrophication potential EP [1] in PO_4e/functional unit	1.83	1.126
Primary energy demand PED in MJ/functional unit	493	991
Resource consumption in kg crude oil equi./functional unit	11.34	12.27

Swine production

Avoided Emissions	Avoided Emissions (Option 2 – Option 1)	Avoided Emissions (Option 3 – Option 1)
Acidification potential AP [1] in kg SO_2e/functional unit	1.121	1.216
Eutrophication potential EP [1] in PO_4e/functional unit	0.353	0.353
Primary energy demand PED in MJ/functional unit	-6	127
Resource consumption in kg crude oil equi./functional unit	0.91	1.74

Case 4 Bio-Mono Ethylene Glycol (MEG) from Renewable Source

India Glycols Limited (IGL)

COMMISSIONER AND PERFORMER OF THE STUDY

The study is commissioned and is performed by India Glycols Limited (IGL).

1. Purpose of the study

The objective of the study is to calculate the avoided emission of greenhouse gas (GHG) during life cycle of Bio route Mono Ethylene Glycol (Bio-MEG) production in India Glycols Ltd (IGL). The Bio-MEG is an alcohol made from agriculture renewable feedstock* instead of MEG production from conventional petro route.

The study focuses on the use of feedstock such as sugarcane molasses and alcohol used to produce Bio-MEG against the petroleum feedstock such as Crude Oil, Natural Gas, Ethylene, etc. in conventional Petro route MEG (Petro-MEG) production. Bio-MEG production using renewable feedstock, saves petroleum feedstock and leads to reduced GHG emissions[1].

When fossil fuels are burned, carbon dioxide along with other GHGs is released directly to the atmosphere. Saving of GHG from production of Bio-MEG is mainly due to use of renewable feedstock as sugarcane molasses for alcohol production followed by Bio-MEG production. Bio-feedstock leads to biogenic CO_2 emissions defined as CO_2 emissions related to the natural carbon cycle (short cycle)[2].

The difference lies in the role of biomass such as wood and organic waste, which plays in sequestering carbon. This sequestration occurs within a relatively short time frame as opposed to the many millions of years it takes fossil fuels to form.

Bio-MEG is slowly catching up with many PET bottle manufacturing and is marketed as environmentally friendly less carbon footprint products.

This study focuses on life cycle GHG emissions and was conducted in alignment with the requirement of *"Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies,"* developed by ICCA and the Chemical Sector Group of the WBCSD and International Standard for LCA *"ISO 14044:2006 Environmental Management - Life Cycle Assessment -Requirements and Guidelines"*.

2. Solutions to compare

2.1. Description of the solutions to compare

The solutions are compared at chemical product level. The Bio-MEG as well as Petro-MEG are exactly same in the quality as ($C_2H_6O_2$) and are used in the same way as raw material for different end products, such as PET bottle & coolant etc,... However the process of production is different as given below (see Figure 1).

Additionally energy use for production of Bio-MEG is majorly renewable energy as Hydro Power for electricity need, Bio-Gas, Bagasse, Spent wash slop fired boilers for steam & electricity generation.

- Grid power of Uttarakhand State India is mainly hydroelectric power.
- Effluent of Ethanol Distillery is converted to Bio-Gas and concentrated Slop having significant calorific value and used in boiler to produce steam as well as partially Fossil fuel is also used.
- This High Pressure Steam is used in turbines to generate electric energy and Medium Pressure & Low Pressure steam from turbine is used in production/process.

In case of Petro-MEG production, the raw material is fossil fuel (heavy GHG load) as well as the energy use for process is fossil fuel fired steam (thermal energy) and electric energy.

The use of the MEG produced through both Petro route and Bio route is same.

2.2. Level in the Value Chain

This study focuses on Bio-MEG production process from bio ethanol and conventional Petro-MEG in the value chain. The use/performance of both MEGs is same. Thus, the level in the value chain of this study is **"chemical product level"** in accordance with the guidelines.

2.3. Definition of the boundaries of the market and the application

MEG is a basic building block used for applications that require Chemical intermediates for Resins, Solvent couplers, Freezing point depression solvents, Humectants and chemical intermediates.

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* Biogenic Feedstock: Biologically based material is used for production and processes.

These applications are vital to the manufacture of a wide variety of products, including Resins, Deicing fluids, Heat transfer fluids, Automotive antifreeze and coolants, Water-based adhesives, Latex paints and asphalt emulsions, Electrolytic capacitors, Textile fibers, Paper, Leather, etc.

MEG is used worldwide. Global demand for MEG is estimated to be 22 million tonnes in 2012 with a capacity of 28 million tonnes[3]. The demand for MEG continues to increase steadily and is estimated to reach 29 million tonnes by 2016[4]. There is around 70 million tonnes demand of PET globally and have 3% as a conservative demand of PET use Bio-MEG. For this 3% PET, there is requirement of 600000 tonnes of Bio-MEG and against it there is availability of around 250000 tonnes of Bio-MEG globally to cater the need as per scenario of 2015. IGL alone caters for around 150000 tonnes of Bio-MEG out of this total available Bio-MEG and rest around 100000 tonnes sourced from other bio route of Bio-MEG. By 2018, it is expected that there will be rise in demand of PET having Bio-MEG, to 4 to 5% globally and will be looking for more Bio-MEG availability[5].

3. Functional unit and reference flow

3.1. Functional unit

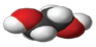
For this case study, the functional unit is defined as **One Metric Ton (MT) of MEG produced from cradle to gate**.

- Process of Bio-MEG production from renewable feedstock /bio route
- Process of Petro-MEG production from petroleum feedstock/petro route

End-uses of MEG (Bio route / Petro route) may vary from use as an intermediate for the manufacture of other chemicals, commercial products, or certain formulated consumer products, thus service life of MEG produce through petro route or bio route is same.

3.2. Reference flow

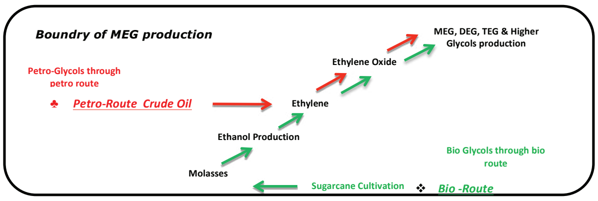
The final MEG produced through Bio route or Petro route are having same chemical formula and quality. Reference flow is one **Metric** ton of MEG (Petro route/Bio route).

Molecular formula of MEG: $C_2H_6O_2$ Molecular Structure of MEG : 

4. Boundary setting

In this study, all relevant processes affected by the production of MEG from cradle to gate are analysed. This study includes agricultural cultivation of sugarcane as well as excavation of crude oil.

FIGURE 1 - MEG PROCESS STEPS OF BIO-MEG (BIO ROUTE) V/S CONVENTIONAL PETRO-MEG (PETRO ROUTE)



The process steps of Bio-MEG

Sugarcane is processed in sugar plant. Sugar, bagasse and sugarcane molasses are produced. Sugarcane molasses from sugarcane is converted into ethanol by fermentation & distillation in distillery. Ethanol is converted to ethylene through the Ethanol Dehydration Reactor. The ethylene from the Ethanol Dehydration Reactor is processed with oxygen to make ethylene oxide which is then hydrolysed to produce MEG and higher molecular weight glycols including di-ethylene glycol (DEG), tri-ethylene glycol (TEG) and heavy glycols (HG).

The process steps of Petro-MEG

The main method of production of MEG is from naphtha, mainly derived from crude oil. Naphtha with steam is fed into a cracker unit where ethylene and other co-products are made. The ethylene from the cracker unit is separated from the co-products and processed with oxygen to make ethylene oxide which is then hydrolysed to produce MEG and higher molecular weight glycols including DEG and TEG[6].

After production of Ethylene, the process is identical till MEG production, but there is a technological difference in the process. Downstream use of MEG is identical as quality of both Bio-MEG and Petro-MEG is same.

The study covers the life cycle of MEG production with bio route and with conventional petro route from cradle to gate. The system boundary consists of “Production of MEG”. This process consists not only of “Productions of MEG”, but also of “Raw material production process” used for production of MEG.

Details of processes and sub-processes are given below:

A. Bio-MEG production
  - Process block of Sugarcane Cultivation
  - Process block of Bagasse, Sugar and Molasses production

- Process block of Ethanol production
- Process block of air separation unit (Air Separation Unit for Oxygen)
- Process block of Thermal & Electrical Energy production
- Process block of Bio-Glycols (Bio-MEG, Bio-DEG, Bio-TEG and Bio-HG) Production

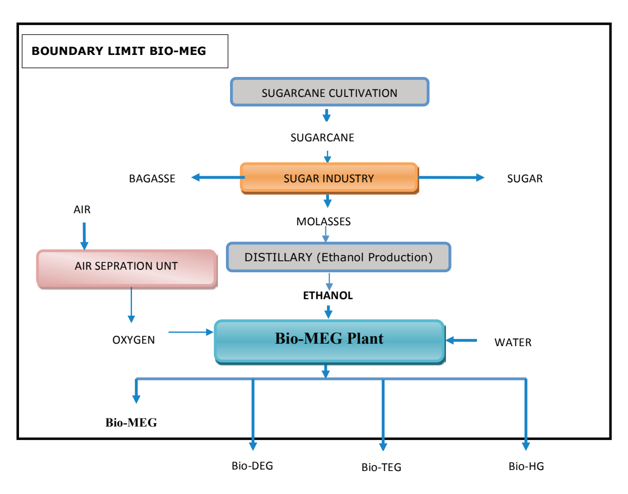
B. Petro-MEG production

- Process block of crude extraction
- Process block of Natural Gas (NG) & Crude refining
- Process block of Ethylene production
- Process block of air separator unit (Air Separation Unit for Oxygen)
- Process block of Ethylene Oxide production
- Process block of Glycols (MEG, DEG, TEG & HG) Production

As shown in system boundary of Bio-MEG production process starts from sugarcane cultivation and ends at Bio–MEG, Bio-DEG, Bio-TEG and Bio-HG production.

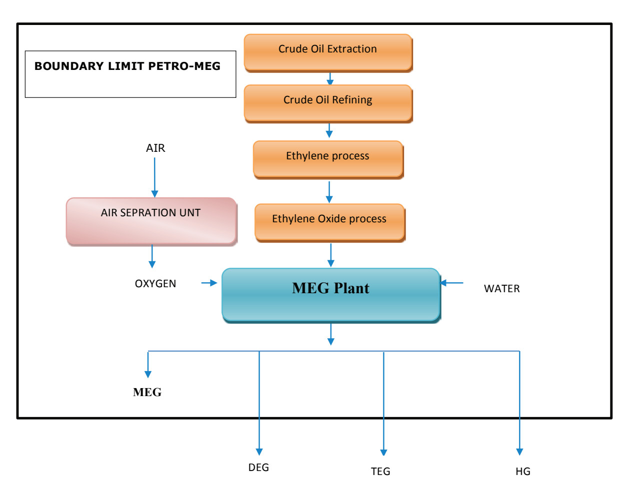
The system boundary of Bio-MEG study covers from cultivation of Sugar cane, transportation of sugarcane to sugar plant, production of molasses, production of ethanol, transportation of ethanol and finally production of Bio-MEG. The study covers the entire life cycle of the Bio-MEG production from cradle to gate, i.e. sugarcane cultivation to Bio-MEG production.

FIGURE 2 - SYSTEM BOUNDARY OF BIO-MEG PRODUCTION PROCESS



The system boundary of Petro-MEG covers from crude oil extraction, ethylene production, ethylene oxide production and finally conventional MEG production. The study covers the entire life cycle of the Petro-MEG production from cradle to gate i.e. crude oil extraction to MEG production.

FIGURE 3 - SYSTEM BOUNDARY OF PETRO-MEG



5. Calculation methodology and data

5.1. Methods and formulas used

The study is chemical product level and covers from cradle-to-gate. GHG emissions from the Production of MEG i.e.

- CO_2e emissions during the phase of raw material procurement to the manufacture of MEG from cradle to gate

Global Warming Potential (GWP) is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide whose GWP is standardized to 1.

5.2. Allocation

When a process has more than two valuable outputs, it becomes necessary to assign the impacts associated with the energy, material, transportation etc. to each of the output using mass, energy, or economic value as the metric. Allocation is carried out in line with ISO 14040:2006 & ISO 14044:2006. The study handles allocation issues by 'mass-economic' system in the process block of power generation. In sugar production system, molasses is 5% by weight, sugar is 10% by weight, bagasse is 30% by weight and the rest is water. But the cost difference among these products is very wide. Sugar has approximately 10 times higher price than bagasse and approximately 6 times higher price than molasses. Using mass allocation only would have given a distorted result. Due to this reason, mass economic allocation method has been used**[7]**. However 'mass allocation' systems have been used for production of MEG. In the MEG production, not only MEG, but also DEG, TEG and Heavy Glycols are produced simultaneously, where MEG is more than 90 % weight, DEG is less than 6% by weight and the rest is TEG and Heavy Glycols.

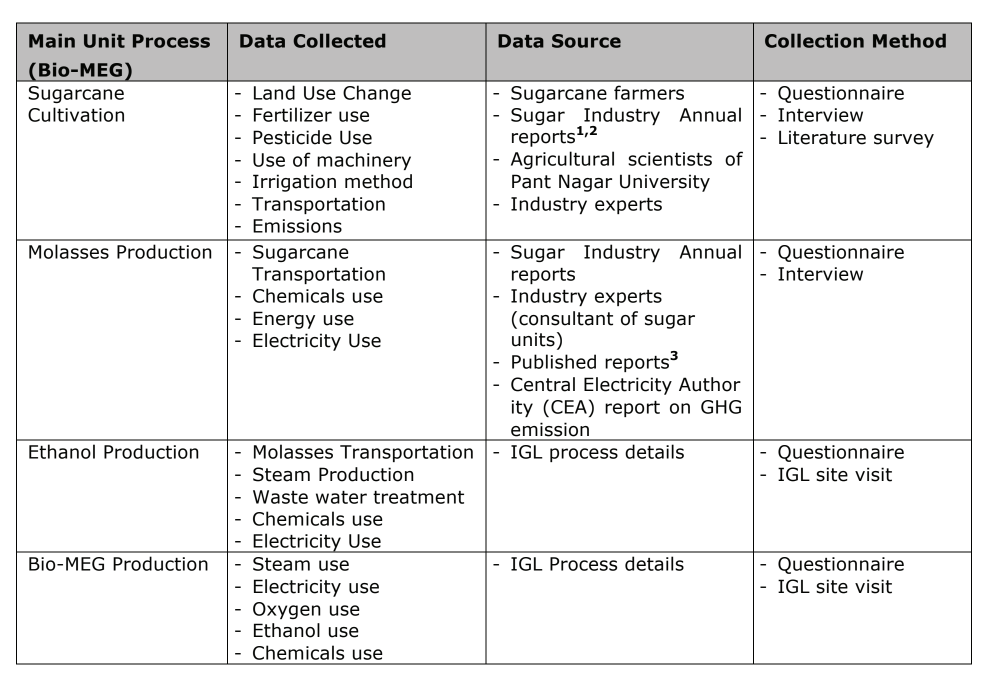
5.3. Data sources and data quality

A cradle to gate LCA of Bio-MEG and GHG emission in the life Cycle of MEG (whether it is Bio-MEG or Petro-MEG), conducted by IGL, are mainly focused in this case study. Actual production process data of IGL is taken for Bio-MEG production from ethyl alcohol & ethyl alcohol production from sugar cane molasses (a byproduct of sugar plant).

IGL collected the data of Bio-MEG from Uttarakhand state of India in North India and collected by Questionnaires, interactions with industry experts, Sugar Manufacturers Association, study of published report and research papers on similar topics, economic surveys etc. in year 2010 to 2011 and updated in 2013-2014. The data quality were considered in accordance with ISO 14044 requirement. All the data used for Bio-MEG production are reproducible because IGL is certified with Quality Management System (ISO 9001:2008). Under the system, the data have been managed and recorded properly and traceable.

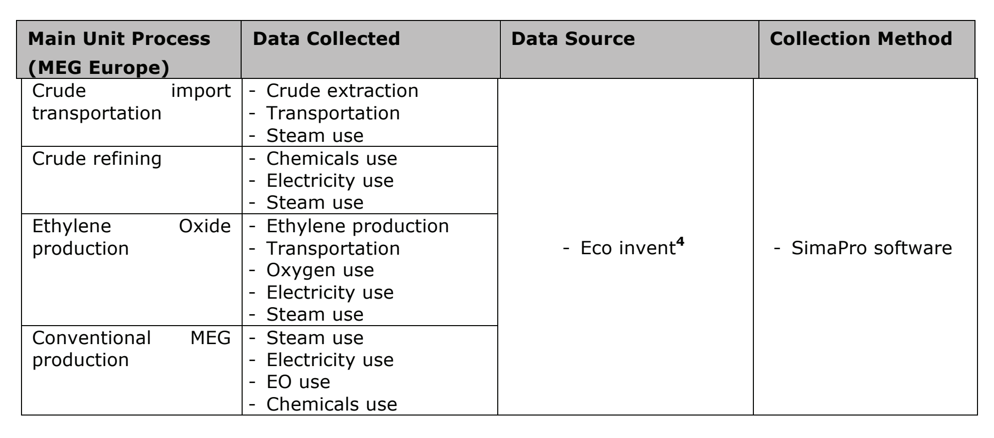
Because of LCA data insufficiency in India, Eco Invent data were taken for Petro-MEG production. The Eco Invent data of Petro-MEG for this study are mainly presented plants in Europe and are of the year 2010-2011 and the last updated in 2012.

DATA SOURCES AND COLLECTION METHODOLOGY FOR BIO-MEG PRODUCTION



Main Unit Process (Bio-MEG)	**Data Collected**	**Data Source**	**Collection Method**
Sugarcane Cultivation	- Land Use Change - Fertilizer use - Pesticide Use - Use of machinery - Irrigation method - Transportation - Emissions	- Sugarcane farmers - Sugar Industry Annual reports[1,2] - Agricultural scientists of Pant Nagar University - Industry experts	- Questionnaire - Interview - Literature survey
Molasses Production	- Sugarcane Transportation - Chemicals use - Energy use - Electricity Use	- Sugar Industry Annual reports - Industry experts (consultant of sugar units) - Published reports[3] - Central Electricity Authority (CEA) report on GHG emission	- Questionnaire - Interview
Ethanol Production	- Molasses Transportation - Steam Production - Waste water treatment - Chemicals use - Electricity Use	- IGL process details	- Questionnaire - IGL site visit
Bio-MEG Production	- Steam use - Electricity use - Oxygen use - Ethanol use - Chemicals use	- IGL Process details	- Questionnaire - IGL site visit

DATA SOURCES AND COLLECTION METHODOLOGY FOR PETRO-MEG PRODUCTION IN EUROPE



Main Unit Process (MEG Europe)	**Data Collected**	**Data Source**	**Collection Method**
Crude import transportation	- Crude extraction - Transportation - Steam use	- Eco invent[4]	- SimaPro software
Crude refining	- Chemicals use - Electricity use - Steam use		
Ethylene Oxide production	- Ethylene production - Transportation - Oxygen use - Electricity use - Steam use		
Conventional MEG production	- Steam use - Electricity use - EO use - Chemicals use		

Geographic region for production of Bio-MEG is Uttarakhand state in North India. The data was collected by IGL. Geographic region for production of Petro-MEG is Europe. Data of Petro-MEG is readily available to all over the world as eco invent data.

Technology of Petro-MEG production is largely same as Bio-MEG production after production of Ethylene. Major difference is feedstock. Bio-MEG's feedstock is Sugarcane molasses followed by Bio-Ethanol and Petro-MEG uses crude oil followed by ethylene as feedstock.

For Bio-MEG production process block is prepared based on available data of IGL. For Petro-MEG production process block data of eco invent.

Bio-MEG process block data is taken based on the data of adequate period of time with even out the normal fluctuation. For Petro-MEG production process block of eco invent where completeness is declared and available to all.

The source of data of Bio-MEG process block is of the under study area (India Glycols). For Petro- MEG production data used is from eco invent which is directly referred.

6. Results

6.1. Avoided emissions

The comparative main result for Bio-MEG with Petro-MEG is shown in Table 1. IPCC 2013, which is an update of the method IPCC 2007, is used to analyse CO_2e.

- <A1> in case of Bio-MEG production from Cradle to Gate,
- <A2> in case of Petro-MEG produced from Cradle to Gate,

The GHG emission for 1 MT of MEG production (bio route and conventional petro route) process are shown in Table 1;

TABLE 1 - COMPARATIVE CHARACTERIZATION RESULTS FOR BIO-MEG AND PETRO-MEGS AS PER IPCC 2013 V1.00 / CHARACTERIZATION

Impact Category	Unit	Bio- MEG <A1>	Petro-MEG <A2>
IPCC GWP 100a	Kg. CO_2 eq.	1221	1628

FIGURE 4 - GHG EMISSION OF BIO-MEG AND PETRO-MEG

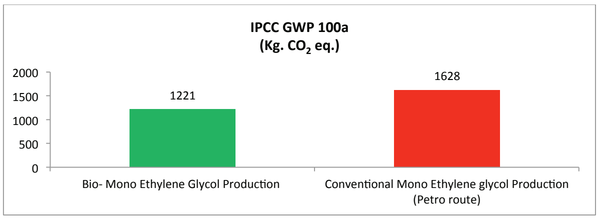
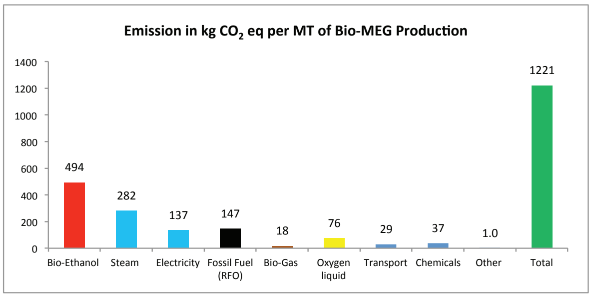


Figure 4 shows the total CO_2 emission generated from Bio-MEG production and from Petro-MEG. The results of the study are presented according to the six Kyoto Protocol gas classifications in CO_2 equivalents for Bio-MEG production at IGL and for Petro-MEG production. These are compared with each other.

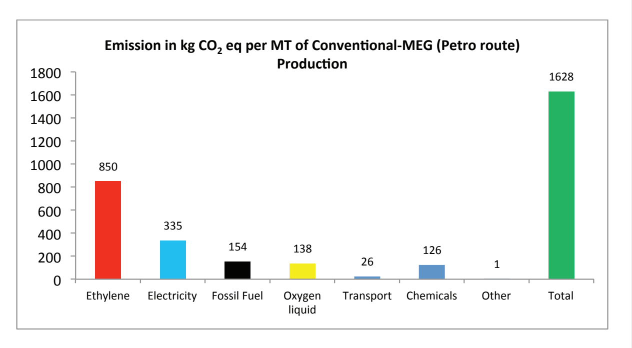
FIGURE 5 - CO_2eq EMISSIONS WHILE MANUFACTURING OF BIO-MEG (CRADLE TO GATE)



The total CO_2 generated is 1221 kg CO_2 equivalents per MT of Bio-MEG production. Process wise details emission of Bio-MEG production is shown in Figure 5. It shows that major GHG load comes from Bio-Ethanol from molasses production followed by electricity consumed, steam production and heat produced from residual fuel oil (RFO). GHG impacts of Bio-Ethanol production from molasses, spent wash treatment, Steam production and electricity are main contributors to GHG load of Bio-Ethanol. Residual fuel oil and Bio-gas are burnt in the process heater as fuel for superheating steam.

Spentwash generated in the process of distillery (Ethanol Plant). Spent wash is partially used for bio-gas generation and partially concentrated as slop (concentrated spent wash). These renwable fuel (biogas & slop i.e. concentrated spent wash) have a good calorific value and use as fuel in boiler with coal. Aproximately 23% fossil fuel (coal) and 73% renewable fuel (bio-gas and concentrated spent wash i.e. slop) are used as fuel in boiler for steam generation followed by electricity generation.

FIGURE 6 - CO_2eq EMISSIONS WHILE MANUFACTURING OF PETRO-MEG (CRADLE TO GATE)



The total CO_2 generated is 1628 kg CO_2 equivalent per MT of Petro-MEG production. Process wise details emission of Petro-MEG production is shown in Figure 6. It shows that major GHG load comes from Ethylene from crude oil production followed by electricity consumed in process and Ethylene Oxide produced from Ethylene.
The Eco Indicator 99 study has been used for the environmental impact categories: acidification, nutrient enrichment (eutrophication), land use, climate change, ozone layer deplition & Radiation etc. With refrence to analysis as per Eco Indicator 99 methodology given in annexure 1, the environmental impacts of Bio-MEG in the life cycle are less than Petro-MEG for the environmental parameter of radiation, ozone layer, ecotoxicity & land use. Acidification/Eutrofication impact is traced to sugarcane cultivation. Use of fertilizers has become reason of neutrient enrichment. Although it will not have any impact on product and it will be there, as sugarcane cultivation is need of sugar plant for producing sugar and molasses is a byproduct.

The avoided emissions are calculated as the difference between the emissions of Bio-MEG with Petro-MEG production.

The results show below that the avoided emissions per MT of MEG production is dominated by the GHG emissions during production stage. Comparing the results of the two alternatives demonstrates that the Bio-MEG production has a lower carbon footprint and thus reduces GHG emissions.

The difference of GHG emissions in MEG production with bio route is predominantly due to use of renewable material (sugarcane molasses) as raw material which is cultivated again.

The GHG emission is higher in MEG production with petro route as fossil fuel as raw material is used to produce MEG. Avoided emission of Bio-MEG production compared to Petro-MEG production is 407 kg CO_2eq/MT MEG production.

6.2. Scenario analysis

Base case is calculated with the assumption of no future change. The avoided emissions per unit MEG production in 2020 will also be largely same. The quantity of the Bio-MEG production in 2020 will be based on demand forecast and it is expected that there will be rise in demand of Bio-MEG.

7. Significance of contribution

Use of Sugarcane molasses as feedstock makes an **"extensive"** contribution to reduced GHG emissions in Bio-MEG production.

The avoided emissions calculated in this study are attributed with special emphasis on production stage at chemical plant/industry.

8. Review of results

"The Comparative Life Cycle Assessment of Bio-MEG from sugarcane molasses with conventional Petro-MEG from fossil fuel" report has been peer reviewed by LCA experts using the methodology IPCC GWP 2007a**[12]** as per ISO 14040:2006**[13]** & 14044:2006 guidelines**[14]** in 2011. Later on the same study is updated as per the revised methodology GWP 100a IPCC 2013. The study consist of production part of MEG from cradle to gate.

TABLE 2 - TABLE SHOWING THE RESULTS OF THE CASE STUDY

Emissions per life cycle phase (CO$_2$e)	**Bio-MEG**	**Conventional MEG (Petro route)**	**Avoided Emission**
Raw material extraction & Manufacturing* MEG (A) (Cradle to gate)	<A1> 1221	<A2> 1628	<A2>-<A1> 1628-1221
Total emissions	**P1=** <A1>	**P2=** <A2>	**P2-P1=** (<A2>)- (<A1>) **1628-1221**
Avoided Emission			**407**

* Manufacture: From raw material extraction to manufacture of per MT of MEG production from cradle to gate

9. Study limitations and future recommendations

Life cycle assessment studies are in its infancy in India. There is no India specific database available for most of the materials. It was a strenuous and difficult task to collect data for sugarcane cultivation, molasses production, MEG production etc.. Questionnaires, interactions with industry experts, study of published report and research papers on similar topics, economic surveys etc. were used as data collection methodologies as described in section 5.3 in this report.

In order to complete this study, various scenarios were considered about modelling approaches and calculation methods as below.

- Fertilizers etc. are used for sugarcane cultivation. Detail process of fertilizer are directly taken from Eco invent.
- There have not been significant land use changes in sugarcane cultivation zone of North India, but it will not have impact on CFP/GHG accounting.
- Trash and sugar plant leftovers neither increase nor decrease the carbon content of the soil, but it will not have impact on CFP/GHG accounting as it follows short carbon cycle.
- Various chemicals used in different processes are taken from Ecoinvent data, which have similar impacts in Indian conditions.
- All the sugar mills/distilleries process spent wash used to generate biogas and slop (concentrated spent wash) which are used in boiler for making steam and electricity.

Data of various chemicals and fertilizers used in the IGL process block were filled from Eco invent/USLCI databases available in SimaPro databases with best suitable and reliable assumptions based on qualified estimates, similar site data used for completeness as well as relevant technology data used.

10. Conclusions

The results of the study are presented by using IPCC 2013 GWP100a methodology. The total CO_2 generated is **1221** kg CO_2 equivalents per MT of Bio-MEG production and **1628** kg CO_2 equivalents per MT of Petro-MEG production. The avoided emissions are presented as the difference of GHG emissions over an MEG life cycle (cradle to gate). Avoided emission of Bio-MEG production compared to Petro-MEG production is significant. Avoided emission of Bio-MEG production compared to Petro-MEG production is 407 kg CO_2eq/MT MEG production. A comparison of the two alternatives demonstrates that GHG emissions from Bio-MEG production are lower than from Petro-MEG production. Bio-MEG production has higher impact of acidification/ Eutrofication. Acidification/ Eutrofication impact is traced to sugarcane cultivation, although it will not have any impact on Bio-MEG production. Main reason of using fertilizers in sugarcane cultivation is neutrient enrichment (acidification/eutrofication). It will be there as sugarcane cultivation is need of sugar plant for producing sugar and molasses is a byproduct. As per the comparitive analysis of Bio-MEG LCA using Eco Indicator 99 methodology the parameters, radiation, ozone layer, ecotoxicity & land use have lesser impact on environment compared to Petro-MEG.

Thus, the above results conclude that production of Bio-MEG is a better option from the GHG emission point of view than Petro-MEG.

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12. Appendices

Bio-MEG is also established through analytical testing as given below procedure and result for 100% Biobased MEG.

Bio-MEG is analysed from BETA LAB for Biobased Analysis using ASTM-D6866:
The application of ASTM-D6866[15] to derive a "Biobased content" is built on the same concepts as radiocarbon dating. It is done by deriving a ratio of the amount of radiocarbon (14C) in an unknown sample to that of a modern reference standard. This ratio is calculated as a percentage with the units "pMC" (percent modern carbon). Proportions Bio-based vs. Fossil Based indicated by 14C content.

Biobased Result of IGL Bio-MEG : 100%
Thus analytically proved that Bio-MEG produced in India Glycols Ltd. through 100% bio route source.

Annexure 1

The study addresses the following environmental impact categories: GWP or GHG, resource depletion, acidification, nutrient enrichment (eutrophication), ozone deplition etc. Default characterization factors from Ecoindicator99 and IPCC 2013 GWP100a are applied and the system modeling is performed in SimaPro (LCA software tool). IGL's aim is to be at the forefront of efforts against global threats such as global warming, stratospheric ozone depletion, resource depletion, bioaccumulation and persistent chemicals. In the same regards IGL has carried out the product LCA study as *"Comparative Life Cycle Assessment of Bio-MEG from molasses with MEG from fossil fuel"*. The EcoIndicator99 study for the environmental impact categories for MEG production (bio route and conventional petro route) process is given below;

ENVIRONMENTAL IMPACTS OF BIO-MEG AND CONVENTIONAL MEG AS PER ECO-INDICATOR 99

Impact category	Unit	Bio- Mono Ethylene Glycol Production	Conventional Mono Ethylene Glycol Production
Climate change	DALY	0.00024	0.00033
Radiation	DALY	2.19747E-06	8.86605E-06
Ozone layer	DALY	1.05493E-07	3.20205E-08
Ecotoxicity	PAF*m2yr	201.01	269.39
Acidification/ Eutrophication	PDF*m2yr	48.67	18.59
Land use	PDF*m2yr	16.01	9.99

The Eco - Indicator 99 methodology is a powerful tool to aggregate LCA results into easily understandable and user friendly number or units called Eco-Indicators. This method works on a damage function approach. The damage function presents the relationship between the impact and the damage to human health or to the eco-system or to the resources. The units are:

- Climate change:Damage, expressed in DALY/kg emission, resulting from an increase of diseases and death caused by climate change.
- Radiation: Damage, expressed in DALY/kg emission, resulting from radioactive radiation
- Ozone layer: Damage, expressed in DALY/kg emission, due to increased UV radiation as a result of emission of ozone depleting substances to air.
- Ecotoxicity: Damage to ecosystem quality, result of emission of ecotoxic substances to air, water and soil. Damage expressed as Potentially Affected Fraction (PAF)*m^2*year/kg emission.
- Acidification/ Eutrophication: Damage to ecosystem quality, as a result of emission of acidifying substances and nutrient enrichment. Damage is expressed in Potentially Disappeared Fraction (PDF)* m^2*year/kg emission.
- Land use: Damage as a result of either conversion of land or occupation of land. Damage is expressed in Potentially Disappeared Fraction (PDF)* m^2*year/ m^2 or m^2a.Land use (in manmade systems) has impact on species diversity. Based on field observations, a scale is developed expressing species diversity per type of land use. Both regional effects and local effects are taken into account in the impact category.

With refrence to analysis of Bio-MEG production as per Eco Indicator 99 the environmental impact of Bio-MEG in the life cycle is less than petro route MEG for the environmental parameter of radiation, ozone layer, ecotoxicity & land use. Bio-MEG production has higher impact of Acidification/Eutrofication which is traced to sugarcane cultivation. Use of fertilizers has become reason of neutrient enrichment. Although it will not have any impact on product and it will be there, as sugarcane cultivation is need of sugar plant for producing sugar and molasses is a byproduct.

Case 5 Aircraft materials (CFRP, Carbon Fiber Reinforced Plastic) for weight reduction

Japan Carbon Fiber Manufacturers Association (JCMA)

COMMISSIONER AND PERFORMER OF THE STUDY

The Study was commissioned and performed by the Japan Carbon Fiber Manufacturers Association (JCMA).

1. Purpose of the study

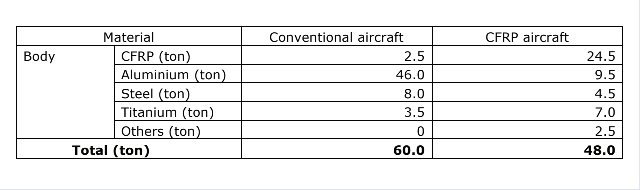
The objective of the study is to calculate the reduction in CO_2 emission during life cycle of an aircraft using more CFRP (carbon fiber reinforced plastic) with a conventional aircraft. CFRP is used in various aircraft components. The use of CFRP reduces the weight of the aircraft while maintaining the same strength and safety. As with automobiles, weight reduction in aircraft directly leads to improved fuel consumption, thereby contributing to a reduction in CO_2 emissions in the transportation sector[1].

2. Solutions to compare

2.1. Description of the solutions to compare

The study compares two alternatives aircrafts, one consists of 3 wt.% CFRP based on Boeing 767 which is called conventional aircraft, the others consists of 50wt% CFRP, that the metal materials is replaced with CFRP, that is called CFRP aircraft. Consequently, CFRP aircraft is reduced 20% weight of Body weight. The composition ratio of material of each aircraft is described as follows (Table 1).

TABLE 1 – COMPOSITION RATIO OF MATERIAL IN THE AIRCRAFT BODY



Material		Conventional aircraft	CFRP aircraft
Body	CFRP (ton)	2.5	24.5
	Aluminium (ton)	46.0	9.5
	Steel (ton)	8.0	4.5
	Titanium (ton)	3.5	7.0
	Others (ton)	0	2.5
Total (ton)		**60.0**	**48.0**

2.2. Level in the Value Chain

This study focuses on flying performance of aircrafts by comparing results from the CFRP aircraft and the conventional aircraft under setting a certain flying conditions in Japan. Thus, the study is made at the end-use level of the value chain.

2.3. Definition of the boundaries of the market and the application

While the market share of the CFPR aircraft in 2009 was almost nothing, it is expected to reach 10 – 20% share in the commercial wide body aircrafts market in 2020.

3. Functional unit and reference flow

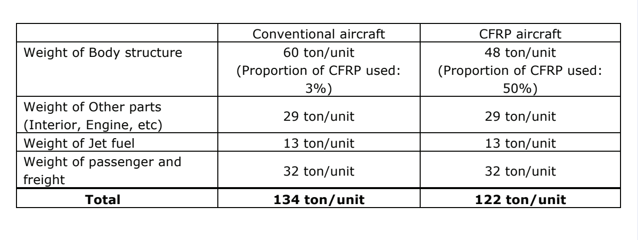
3.1. Functional unit

There are two types of aircrafts as functional unit as shown below, while flying. One conventional aircraft and one CFRP aircraft are operated over the same aviation mileage in Japan, and are operated with same weight of other parts, and with same weight of jet fuel, and with same weight of passenger and freight.

The functional unit and precondition in the study are cited from "The guideline of the calculation of Avoided of CO_2 emission of Japan Chemical Industry Association[2] and Carbon-Life Cycle Analysis (2012) of Japan Chemical Industry Association[3].

The composition weight ratio during the stage of aircraft usage of two alternatives considered in the study is described as follows (Table 2).

TABLE 2 – COMPOSITION WEIGHT RATIO DURING THE STAGE OF AIRCRAFT USAGE OF CONVENTIONAL AIRCRAFT AND CFRP AIRCRAFT IN FLIGHT



	Conventional aircraft	CFRP aircraft
Weight of Body structure	60 ton/unit (Proportion of CFRP used: 3%)	48 ton/unit (Proportion of CFRP used: 50%)
Weight of Other parts (Interior, Engine, etc)	29 ton/unit	29 ton/unit
Weight of Jet fuel	13 ton/unit	13 ton/unit
Weight of passenger and freight	32 ton/unit	32 ton/unit
Total	**134 ton/unit**	**122 ton/unit**

Above two alternatives are considered in the study so as to fulfil the same strength and safety.

Jet fuel consumption based on weight of aircraft.

- Jet fuel consumption of the conventional aircraft is 103 km/L.
- Jet fuel consumption of the CFRP aircraft is 110 km/L.

Flight mileage of service lifetime is defined 500 miles(between Haneda and New Chitose)×2,000 flights/annual×10 years (Service life), based on "Ordinance of Ministry about the about the calculation of the greenhouse gas emission with the business activity of the specified emitter (Japan Ministry of the Environment)[5]".
Reference year of for comparison is year 2007.

3.2. Reference flow

The actual reference flow is confidential and is not shown in $LCCO_2$ Calculation Guidelines for Aircraft from JCMA (The Japan Carbon Fiber Manufacturers Assosiations). The literature only shows composition ratio of the material (see Table1).

4. Boundary setting

The system boundary consists of following three elements shown in Figure 1.

Production of an aircraft

This process consists of not only “Production of Body structure”, but also “Production of other parts” used for production of an aircraft.

Use of an aircraft

This process consists of not only “Flight”, but also “Maintenance” used for use of an aircraft. And the service life is 10 years[5].

Disposal and recycling of an aircraft

This process consists of “Disposal and recycling of an aircraft”.

The CFPR aircraft and the conventional aircraft are considered to have the same process system boundary. At the “Production of Body structure”, there are differences in the composition ratio of CFRP material between the CFRP aircraft and the conventional aircraft.

In detail, the CFRP parts of Body structure of the conventional aircraft and the CFRP aircraft are described as follows. Fuselage Frame, Wings, Vertical/horizontal tails are not identical CFRP parts for two alternatives.

- CFRP parts of the conventional aircraft:
  Aileron, Spoiler, Elevator, Rudder, Engine cowl.
- CFRP parts of the CFRP aircraft:
  Aileron, Spoiler, Elevator, Rudder, Engine cowl, Fuselage Frame, Wings, Vertical/horizontal tails.

5. Calculation methodology and data

5.1. Methods and formulas used

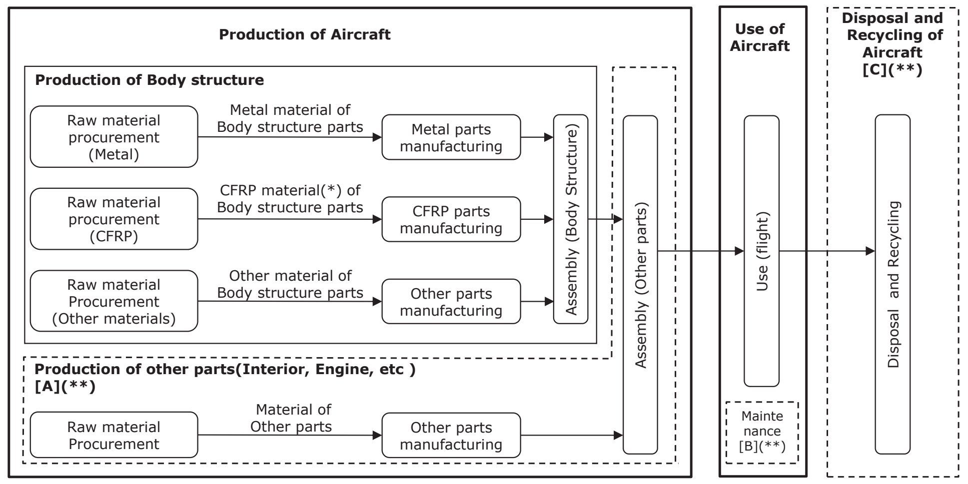
This study starts with a Life Cycle Assessment only focuses on life cycle CO_2 emission as a first step and uses the simplified method. In this study, trade-offs to other environmental impacts are not identified in the screening of LCA.

CO_2 emission from the “Production of other parts (Interior, Engine, etc) [A]” and “Maintenance during the stage of aircraft usage [B]” and “Disposal and Recycling [C]” in Figure 1 are balanced out since this process is identical for two alternatives and they do not change the overall conclusion of this study. The significance of the CO_2 emission being omitted which is the total CO_2 emission of identical part, [A] and [B] make up to 10%[4] of the entire life emission for the CFPR aircraft and the conventional aircraft. The significance of the CO_2 emission being omitted which is the total CO_2 emission of identical part, [C] make up to 2%[6] of the entire life emission for the CFPR aircraft and the conventional aircraft. 2% is estimated by the method written for the literature[6] in changing the precondition (i.e. Assuming that the composition weight ratio of automotive is replaced the composition weight ratio of the CFPR aircraft and the conventional aircraft). The omitting emission of [A] and [B] and [C] do not change the overall conclusion of this study.

The life cycle CO_2 emission is determined by summing up the CO_2 emission in the entire life cycle of an aircraft. The entire life cycle of an aircraft considered in this study are “The stage of raw material procurement – manufacture of body structure materials”, “The stage of manufacture - aircraft assembly of body structure parts”, and ”The stage of aircraft usage”.

Table 3 shows the preconditions setting to calculate the CO_2 emission when the CFRP aircraft and the conventional aircraft fly under the certain flight condition in Japan.

FIGURE 1 - SYSTEM BOUNDARY OF THE CFRP AIRCRAFT AND THE CONVENTIONAL AIRCRAFT



(*) Carbon fiber and Resin
(**) The process/material of [A], [B], and [C] in the broken line is identical for two alternatives in this analysis. These parts are omitted from the calculation.

Table 4 shows the precondition setting to calculate the CO_2 emission in 2020. Three PAN-based Carbon fiber manufacturers in Japan estimated the amount of carbon fiber used for aircrafts in 2020, JCMA (The Japan Carbon Fiber manufacturers Association) calculates "the number of CFRP aircrafts in Japan" from "carbon fiber used for aircrafts" and "carbon fiber used in a CFRP aircraft".

TABLE 3 - PRECONDITIONS APPLIED TO THIS STUDY IN THE STAGE OF AIRCRAFT USAGE

	Conventional aircraft	CFRP aircraft
Weight of Body structure	60tons/unit (Proportion of CFRP used: 3%)	48tons/unit (Proportion of CFRP used: 50%)
Jet fuel consumption*	103 km/L of jet fuel	110 km/L of jet fuel
Lifetime flight mileage	500 miles×2,000 flights/annual×10 years 2,000 flights/annual* 500 miles between Haneda and New Chitose* 10 years (Service life)[5]	
Amount of jet fuel used	155,300kL/unit	145,500kL/unit
CO_2 emissions for jet fuel	2.5kg-CO_2/L[5]	

* Information by a Japanese major airline company

TABLE 4 - PRECONDITIONS OF CFRP AIRCRAFT IN 2020*

Carbon fibre used for aircrafts in2020	900 tons in Japan
Carbon fibre used in a CFRP aircraft	20tons/unit
Number of CFRP aircrafts in 2020	45 units in Japan

* Estimated by three PAN-based Carbon fiber manufacturers in Japan

5.2. Allocation

No allocation was needed in the documented input data.

5.3. Data sources and data quality

This study used secondary data from "Ordinance of Ministry about the about the calculation of the greenhouse gas emission with the business activity of the specified emitter (Japan Ministry of the Environment)[5]", and "the information by a Japanese major airline company as year of 2007". These secondary data listed the literature of "The guideline of the calculation of Avoided of CO_2 emission of Japan Chemical Industry Association[2] and Carbon- Life Cycle Analysis (2012) of Japan Chemical Industry Association[3].

- The time related coverage of the data is based on Japanese domestic data, as year of 2007.
- The geographical coverage is basically Japanese domestic data.
- The technology coverage is based on the statistical value of Japan Chemical Industry Association and is calculated in conformity to the literature above[2],[3].

6. Results

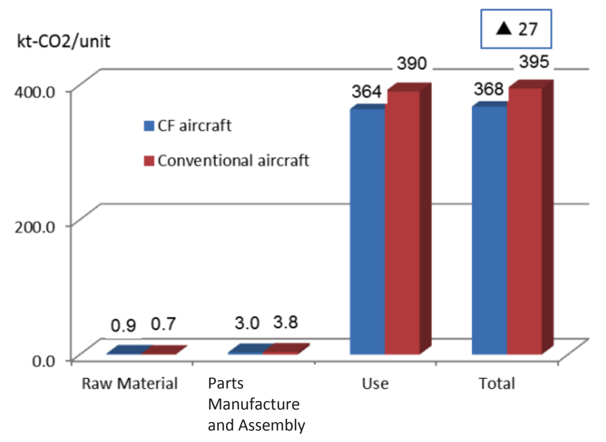
6.1. Avoided emissions

The avoided emission in this study is shown in Table 5 and Figure 2 below. Table 5 shows the avoided CO_2 emissions per aircraft unit. And Figure 2 shows Life cycle CO_2 emissions of CFRP aircraft and Conventional aircraft.

TABLE 5 - THE AVOIDED CO2 EMISSIONS PER AIRCRAFT UNIT (KT-CO2/UNIT)

		CFRP aircraft	Conventional aircraft
CO_2 emissions during the stages of raw material procurement - manufacture of materials of body structure materials (kt-CO_2/unit)		**0.9**	**0.7**
CO_2 emissions during the stage of manufacture - aircraft assembly of body structure parts (kt-CO_2/unit)		***3.0***	***3.8***
During the stage of aircraft usage	Fuel consumption during aviation (km/kℓ-jet fuel oil)	110	103
	Lifetime aviation mileage (miles)	500 miles × 20,000 flights	
	Lifetime amount of gasoline used (kℓ/unit)	145,500	155,300
	CO_2 emissions during combustion of jet fuel (kg-CO_2/ℓ)	2.5	
	CO_2 emissions during the usage stage (kt-CO_2/unit·10 years)	**364**	**390**
CO_2 emissions over the entire life cycle (kt-CO_2/unit·10 years)		**368**	**395**
CO_2 emission abatement (kt-CO_2/unit·10 years)		**▲27**	

FIGURE 2 - LIFE CYCLE CO2 EMISSIONS OF CFRP AIRCRAFT AND CONVENTIONAL AIRCRAFT.



The life cycle CO_2 emissions of CFRP aircraft and Conventional aircraft is as follows. (In this case CO_2 is almost all among other GHG elements.)

CO_2 emissions of the entire life cycle is 368kt-CO_2/unit in the case of CFRP aircraft, while 395kt-CO_2/unit in the case of conventional aircraft. As a result, CO_2 emissions abatement over the entire life cycle is 27 kt-CO_2/unit .

In this case, avoided emissions are mainly influenced in the stage of aircraft usage (i.e. fuel consumption while "flight" process). Weight reduction of aircraft directly leads to improved fuel consumption, thereby contributing to a reduction in CO_2 emissions.

CO_2 emissions during the stage of raw material procurement to aircraft assembly

In the CFRP aircraft, CO_2 emission during the stage of raw material procurement and manufacture of body structure materials is 0.9kt-CO_2/unit, and during the stage of manufacture - aircraft assembly of body structure parts is 3.0kt-CO_2/unit.

In the case of conventional aircraft, the former is 0.7kt-CO_2/unit, and the latter is the latter is 3.8kt-CO_2/unit, respectively.

CO_2 emissions during the stage of aircraft usage

CO_2 emissions during the stage of aircraft usage is 364kt-CO_2/unit in the case of CFRP aircraft, and 390kt-CO_2/unit in the case of conventional aircraft.

6.2. Scenario analysis

Since assumptions on future conditions can have a significant impact on avoided CO_2 emission calculation, a base case is calculated to assume no future change (i.e. use of the actual data available). The CO_2 emission in 2020 is calculated using the data in 2007 listed the literature[2],[3].No scenario analysis on future developments is performed in this study.

7. Significance of contribution

The use of Carbon fiber for aircraft results in the weight reduction and improves fuel efficiency during operation. The weight lightening by CFRP fundamentally contributes to fuel efficiency. Nevertheless, the CO_2 emission avoidance efforts and effect calculated at the end-use level of aircraft are attributed to various partners along the complete value chain, and not only to the chemical industry.

8. Review of results

On June 2, 2011, the case study was presented to a panel consisting of four Japanese experts in the field of LCA. The four experts did not take responsibility for all elements of an LCA peer review, which is described in ISO 14044. The review only focused on the methodology employed to calculate avoided CO_2 emission. The panels understood that the avoided CO_2 emission was achieved by carbon fiber which lightened the weight of the aircraft.

9. Study limitations and future recommendations

This case study shows the avoided CO_2 emission by focusing on the consistence of CFRP material contained in body structure of aircraft. In detail, this study is to assess the avoided CO_2 emission comparing with CFRP aircraft using CFRP by 50% of the body structure and Conventional aircraft using CFRP by 3 % of the body structure. The avoided CO_2 emission is mainly influenced in the use phase. This means that fuel consumption while aircraft flying, is affected by the significant change in the weight of body structure, and fuel efficiency (i.e. the aircraft model). The case study is based on only the specific condition, and assumptions that were set to typical pattern in Japan, and the limitation of the study arising from omitting identical processes (i.e. Production of other parts(Interior, Engine, etc), maintenance, disposal, and recycling).And the study does not consider the increase of fuel efficiency brought by technological improvements until 2020. Consequently the study results are less realistic and transferable to other conditions and to other regions.

10. Conclusions

The avoided emissions are 27 kt-CO_2/unit over 10 years as the difference of CO_2 emission over an aircraft's life cycle. A comparison of the two alternatives demonstrates that the CFRP aircraft has a lower carbon footprint and reduced CO_2 emission. $LCCO_2$ of aircraft is dominated by the use phase of aircraft.

11. References

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12. Appendices

None

Case 6 Materials for fuel efficient tires

Japan Chemical Industry Association (JCIA)

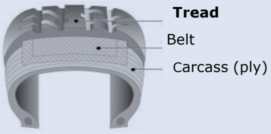
COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned and performed by Japan Chemical Industry Association (JCIA).

1. Purpose of the study

The purpose of the study is to calculate and provide the reduction in greenhouse gas (GHG) emissions during life cycle of automobiles in Japan equipped with fuel efficient tires instead of conventional tires. The study focuses on the chemical products contained in the tire such as synthetic rubber (SBR, styrene-butadiene rubber) and fillers such as carbon black, silica and silane coupling agents. Hence the study shows and quantifies the positive contribution that the chemicals formulation and the specific structure of SBR help the fuel efficient tire reduce fuel consumption in automobile, which leads to reduce GHG emissions.

Improvement in automobiles' fuel consumption has been enabled by the rolling resistance of the tread portion (see right graphic). The tread portion has lowered the rolling resistance significantly. Chemical products help tire performance to meet the competing goals of reducing fuel consumption and to enhance road-gripping performance. The improvement of tire performance comes not only from the entire formulation but also from the specific structure of SBR and the dispersion technology of higher content silica in the rubber. The SBR with the specific structure produced by solution polymerization method, which is a type of synthetic rubber, transforms the physical properties of the tire and reduces the loss of energy caused by tire friction while an automobile is moving. Higher content silica used in fuel efficient tires also contributes to reduce rolling resistance compatible with maintaining grip.



This case study focuses on life cycle GHG emissions and follows the requirements of the document *"Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies (guidelines),"* developed by ICCA and the Chemical Sector Group of the WBCSD.

2. Solutions to compare

2.1. Description of the solutions to compare

The study compares two alternative cars, one is passenger cars and trucks/buses equipped with fuel efficient tires and the other is passenger cars and trucks/buses equipped with conventional tires by focusing on the cars' driving under the traffic condition in Japan. The chemical products contained in tires are almost same, however SBR with specific structure and chemical formulation of tires, especially the silica content are different (see Table 1).

TABLE 1 - COMPOSITION RATIO OF CHEMICAL PRODUCTS IN THE TIRES[2]

Name of the raw materials contained in the tire	**Passenger cars**		**Trucks/buses**	
	Conventional tire	fuel efficient tire	Conventional tire	fuel efficient tire
Rubber (Breakdown)	**100.0**	**100.0**	**100.0**	**100.0**
・Natural rubber	*39.0*	*46.4*	*77.0*	*78.8*
・Synthetic rubber	*61.0*	*53.6*	*23.0*	*21.2*
Silica	**1.0**	**16.9**	**1.0**	**2.8**
Carbon black	**50.0**	**41.3**	**52.0**	**47.3**
Process Oil	**8.0**	**9.6**	**2.0**	**1.8**
Others	**47.0**	**50.6**	**62.0**	**60.6**

Note: Mass of rubber is assumed as 100.
Example of Conventional tire for Passenger cars: Rubber 100g, Silica 1g, Carbon black 50g, Process Oil 8g, Others 47g and Total 206g

2.2. Level in the Value Chain

This study focuses on driving performance of passenger cars and tracks/buses by comparing results from fuel efficient tires and from conventional tires under setting a certain driving conditions in Japan. Thus, the level in the value chain of this study is "the end-use level" in accordance with the guidelines.

2.3. Definition of the boundaries of the market and the application

The quantity of fuel efficient tires sold in Japan in 2010 is 17 million and that of conventional tires is 74 million. The market share for fuel efficient tires in 2010 was 19%[1].The quantity of fuel efficient tires expected to be sold in Japan in 2020 is 78 million and that of conventional tires is 13 million. The expected market share for fuel efficient tires in 2020 will be 86%.

The study forecasts year of 2020, based on technology data available as of 2012. By using the above data, JCIA assumed that automobile market in Japan stays flat and the total number of fuel efficient tires and conventional tires remains the same between in 2010 and in 2020.

3. Functional unit and reference flow

3.1. Functional unit

Functional unit is below two types of automobiles while moving. Automobiles with fuel efficient tires and those with conventional tires were operated over the same distance and with the same passenger or freight weight. The functional unit and service condition in the study is cited from “LCCO$_2$ Calculation Guidelines for tires, Ver. 2.0 of the Japan Automobile Tire Manufacturers Association, Inc.”[2].

- Passenger cars to carry the passengers (**PCR**) with 4 tires
- Trucks/buses to carry the passengers/freight (**TBR**) with 10 tires

Above two alternatives considered in the study fulfil the same function and meet the minimum quality requirements (including regulation and standard) concerning mechanical and safety properties[3].

Service life is defined below as driving distance[2], based on one tire’s service life. During the service life, proper air pressure in a tire and tire rotation are maintained daily. Service life of tires is assumed to be the same between fuel efficient tires and conventional tires.

- The service life of **PCR** is 30,000km
- The service life of **TBR** is 120,000km

3.2. Reference flow

The actual reference flow is confidential and is not shown in LCCO$_2$ Calculation Guidelines for tires, Ver. 2.0 of the Japan Automobile Tire Manufacturers Association, Inc.[2]. The literature only shows composition ratio of the chemical products contained in the tire (see Table 1).

4. Boundary setting

The system boundary consists of following three elements shown in Figure 1.

Production of automobile

This process consists not only of “Productions of tire”, but also of “Raw material procurement to manufacture of materials other than tire” used for production of automobile, “Production of parts and assembly other than tire”, and “Distribution of parts other than tire”.

Use of automobile

Driving” process of automobile is considered. The service life is one tire’s duration of life. Therefore maintenance of automobile is not included.

Disposal/recycling of automobile

Both “Disposal of tire” and “Disposal/recycling of raw materials and parts other than tire” are considered.

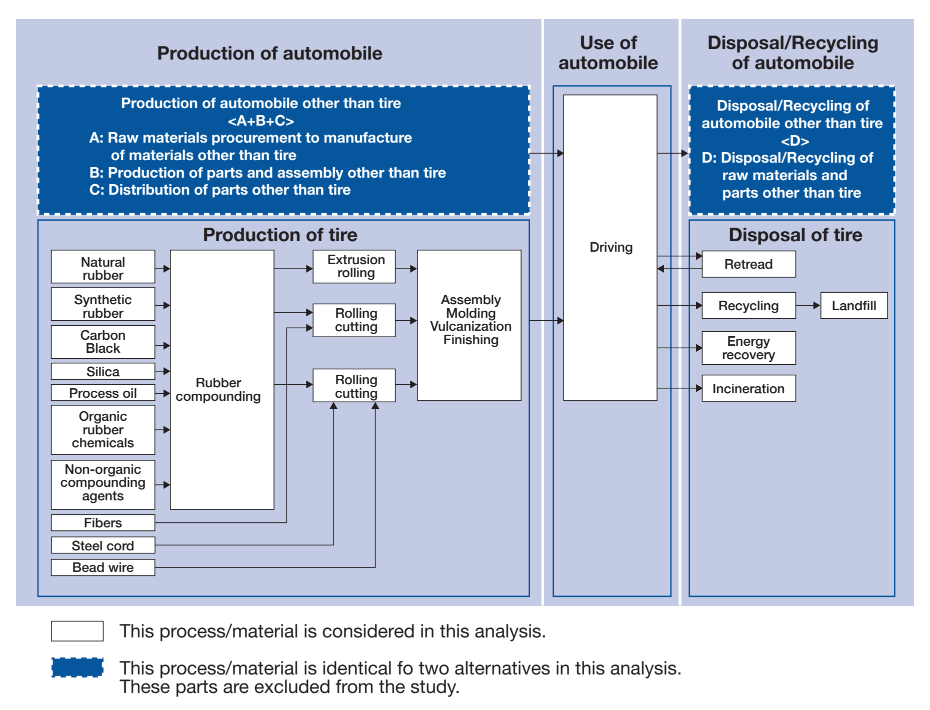
PCR and **TBR** with fuel efficient tires and those of conventional tires are considered to have same process system boundary. At the “production of tire”, there are differences in the structure of SBR and composition ratio of chemical products between fuel efficient tires and conventional tires.

5. Calculation methodology and data

5.1. Methods and formulas used

The study starts with an analysis restricted to GHG as a first step and uses the simplified calculation method. In the study, trade-offs to other environmental impacts are not identified in the screening LCA.

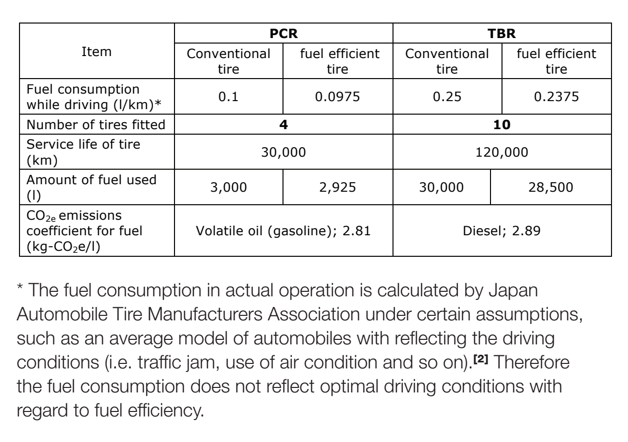
FIGURE 1 - SYSTEM BOUNDARY OF AUTOMOBILES WITH FUEL EFFICIENT TIRES AND WITH CONVENTIONAL TIRES



GHG emissions from the "Production of automobile other than tire <A+B+C>" and "Disposal/recycling of automobile other than tire <D>" in Figure 1 are balanced out since these processes are identical for the two alternatives and they do not change the overall conclusion of the study. The significance of the emissions being omitted which is the total emissions of identical parts, <A+B+C> and <D> make up 20%[4] of the complete life emissions for **PCR** and 8%[5] of the complete life emissions for **TBR**. The omitting emission of <A+B+C> and <D> does not change the overall conclusion of the study.

Table 2[2] shows the condition setting to calculate the GHG emission when tires are equipped with automobiles (**PCR** and **TBR**) and the automobiles run under the certain driving condition.

TABLE 2 - AUTOMOBILES' OPERATING CONDITIONS IN THE USE PHASE[2]

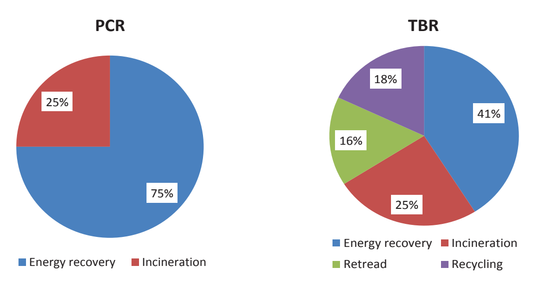


Item	PCR		TBR	
	Conventional tire	fuel efficient tire	Conventional tire	fuel efficient tire
Fuel consumption while driving (l/km)*	0.1	0.0975	0.25	0.2375
Number of tires fitted	4		10	
Service life of tire (km)	30,000		120,000	
Amount of fuel used (l)	3,000	2,925	30,000	28,500
CO_{2e} emissions coefficient for fuel (kg-CO_2e/l)	Volatile oil (gasoline); 2.81		Diesel; 2.89	

* The fuel consumption in actual operation is calculated by Japan Automobile Tire Manufacturers Association under certain assumptions, such as an average model of automobiles with reflecting the driving conditions (i.e. traffic jam, use of air condition and so on).[2] Therefore the fuel consumption does not reflect optimal driving conditions with regard to fuel efficiency.

Figure 2 shows the disposal/ recycling ratio of used tires for **PCR** and **TBR**. 75% of used tires of **PCR** are utilized as heat and 25% of those are incinerated. Regarding **TBR**, in addition to utilization of heat and incineration, retread and material recycling are conducted.

FIGURE 2 - END OF LIFE SCENARIO



Note: In case the simplified calculation method has been used this should be mentioned explicitly in the report (at the beginning and in section 6), and the report requirements at page 24 of the guidelines should be taken into account. http://www.icca-chem.org/ICCADocs/E%2CC%20LG%20guidance_FINAL_07-10-2013.pdf

5.2. Allocation

Credits for the heat recovery and for recycling in Figure 2 to offset energy and materials in production are applied in the calculation for each tire type

5.3. Data sources and data quality

The study uses the secondary data from the literature of "LCCO$_2$ Calculation Guidelines for tires, Ver. 2.0 of the Japan Automobile Tire Manufacturers Association, Inc."[2].

- The time related coverage of the data is based on actual consumption of energy and actual production volume of synthetic rubber from the members of Japan Automobile Tire Manufacturers Association, as of year of 2010.
- The geographical coverage is basically Japanese domestic data.
- The technology coverage is based on the statistical value of Japan Automobile Tire Manufacturers Association and is calculated in conformity to the literature above[2].

6. Results

6.1. Avoided emissions

The Table 3 shows the avoided emissions for **PCR** and **TBR** with major example of fuel efficient tires and those with major example of conventional tires by focusing on tires.

A,B,C and D, which are CO$_2$e emissions at each phase other than tires used in automobiles, are identical between fuel efficient tires and conventional tires. Thus, they are balanced out in calculating the difference of emissions at each phase based on the simplified calculation method.

The results show below that the avoided emissions at the use phase of automobiles are dominated by the GHG emissions related to fuel consumption. The impacts of manufacture, production, distribution and disposal/ recycling of automobiles are small. Comparing the results of the two alternatives demonstrates that the automobile with fuel efficient tires has a lower carbon footprint and thus reduces GHG emissions.

TABLE 3 - THE AVOIDED CO_2e EMISSIONS PER AUTOMOBILE UNIT (KG-CO_2e/UNIT)

	PCR with 4 tires			TBR with 10 tires		
phase	Fuel efficient tires a	Conventional tires b	Avoided CO_{2e} emission (b-a)	Fuel efficient tires a	Conventional tires b	Avoided CO_{2e} emission (b-a)
Manufacture*	95.6 + A	100 + A	4.4	1397 + A	1480 + A	83
Production*	28.0 + B	31.2 + B	3.2	352 + B	356 + B	4
Distribution	6.0 + C	6.4 + C	0.4	101 + C	104 + C	3
Use phase*	**8,219**	**8,430**	**211**	**82,365**	**86,700**	**4,335**
disposal/recycling	2.8 + D	11.6 + D	8.8	-309 + D	-311 + D	-2
Entire life cycle	8,351.4+ A+B+C+D	8,579.2+ A+B+C+D	**227.8**	83,906+ A+B+C+D	88,329+ A+B+C+D	**4,423**

*Manufacture A: From raw material procurement to manufacture of material
*Production B: From parts production to parts assembly
*Use phase C: CO_2e emissions per automobile unit during the usage phase (kg-CO_2e/unit)

Note:

A: CO_2e emissions during the phase of raw material procurement to the manufacture of materials other than tires used in automobiles

B: CO_2e emissions during the phase of the production of parts other than tires

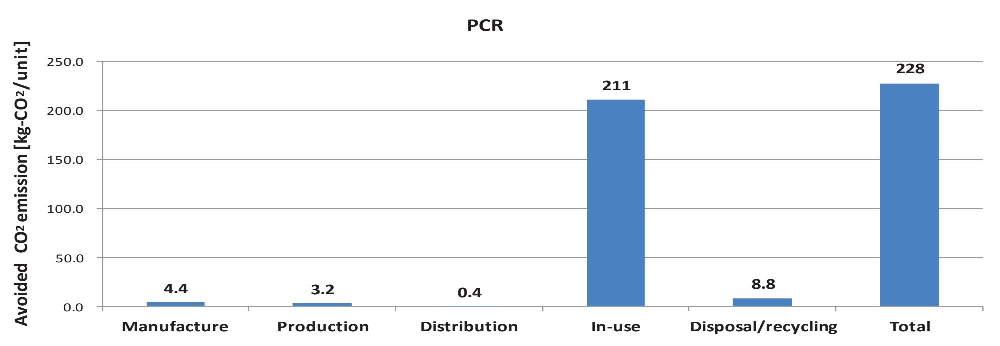
C: CO_2e emissions during the phase of distribution of parts other than tires

D: CO_2e emissions during the phase of the disposal/recycling of raw materials and parts other than tires

The case of one PCR unit, equipped with 4 tires

- Avoided CO_2e emissions per PCR unit: 228kg-CO_2e
- Avoided CO_2e emissions per one tire: 57.0kg-CO_2e

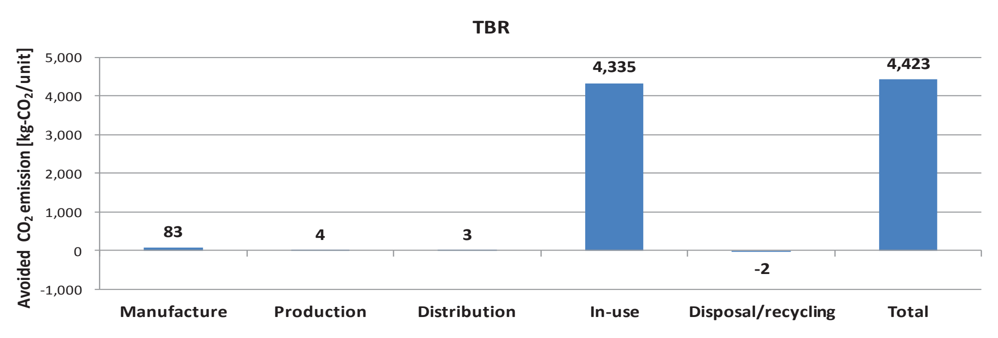
FIGURE 3 - AVOIDED CO_2e EMISSIONS PER THE PCR UNIT



The case of TBR unit, equipped with 10 tires

- Avoided CO_2e emissions per TBR unit: 4,423 kg-CO_2e
- Avoided CO_2e emissions per one tire: 442.3 kg-CO_2e

FIGURE 4 - AVOIDED CO_2e EMISSIONS PER THE TBR UNIT



The quantity of fuel efficient tires sold in Japan in 2010 is 17 million and that of conventional tires is 74.195 million[1]. Accorind to the "Fuji Chimera Research institute" market forecast in 2011[1], the fuel efficietn tires market in Japan was expected to be sold 70 million tires in 2015.

JCIA elicited demand forecast of fuel efficient tires in 2020 is 78 million and that of conventional tires is 13.195 million by using the market forecast and by assuming 2% annual growth in Japan.

The breakdown of the fuel efficient tire's demand in 2020 is as follow;

- The number of tire for PCR: 73 million tires
- The number of tire for TBR: 5 million tires

Total of fuel efficient tire's demand is 78 million.

Final avoided CO_2e emissions are calculated with the one tire's avoided CO_2e emissions brought by Figure 3 and Figure 4 and with the above market forecast in 2020.
The breakdown of the avoided CO_2e emissions from fuel efficient tire is as follow;

- 57.0 kg-CO_2e(One tire for PCR) × 73 million tires = 4.16 million t-CO_2e
- 442.3 kg-CO_2e(One tire for TBR) × 5 million tires = 2.21 million t-CO_2e

Total of avoided CO_2e emissions from fuel efficient tires' is 6.37 million t-CO_2e.

6.2. Scenario analysis

Assumptions on future conditions could have had a significant impact on avoided emissions calculation. Therefore, a base case is calculated to assume no future change (i.e. use of latest actual data). The avoided emissions per automobile unit in 2020 is caluclated using the data[2] in 2012. The quantity of the fuel efficient tire expected to be sold in 2020 is based on demand forecast. No scenario analysis on future developments is performed in this study.

7. Significance of contribution

The focus product of this study is the chemical products formulation contained in the tire, such as SBR and fillers such as carbon black, silica and silan coupling agents. In addition, the technology by chemical industry, such as specific structure of SBR and the dispersion of high content silica in the rubber contributes to the GHG emissions avoidance effect as a key solution. The above chemical substances are parts of key component of tires that reduce the loss of energy caused by tire friction while automobiles are driving. Therefore the contribution of the chemical product to the solution is "extensive" in accordance with the guidelines.

Nevertheless, the GHG emissions avoidance efforts and effect calculated at the end-use level of automobiles are attributed to various partners along the complete value chain, and not only to the chemical industry.

8. Review of results

The study was reviewed by four Japanese experts in the field of LCA. The review focused on the methodology. While it did not include all the elements described in ISO 14044, the review did not take exception to the calculations of the GHG emissions. Section 12 Appendices – Results from the critical review shows the detail.

9. Study limitations and future recommendations

This case study shows the avoided emissions by focusing on the chemical products contained in tire. The avoided emissions are mainly resulted from the use phase of automobiles. This means that fuel consumption while automobile driving, is heavily influenced by tires' performance, such as rolling resistance and road-gripping performance. The results are also affected by the car model and driving conditions. The case study is based on a specific conditions and assumptions that were set to demonstrate an average situation in Japan. The study does not consider the increase of fuel efficiency brought by technological improvements and does assume that the fuel efficiency of cars stays stable until 2020. Consequently the study results are less realistic and transferable to other conditions and to other countries.

10. Conclusions

This study calculates and provides the reduction in GHG emissions during life cycle of automobiles in Japan equipped with fuel efficient tires instead of conventional tires by using the secondary data and simplified calculation methodology. The main focus of the study was to demonstrate the contribution of chemical products and technology in fuel efficient tires to GHG emissions reduction and a lower carbon footprint. The result of this analysis is dominated by the use phase of automobiles driving.

11. References

[1] Fuji Chimera Research Institute, Inc.. Current Situation Concerning Plastic Highly Functional Materials and Future Outlook in 2011, Fuji Chimera Research Institute, Inc. Tokyo January 2011

[2] Japan Automobile Tire Manufacturers Association, Inc.. $LCCO_2$ Calculation Guidelines for tires, Ver. 2.0 of the Japan Automobile Tire Manufacturers Association, Inc. (general incorporated association)

April 2012. Available (2014-11-18) from: http://www.jatma.or.jp/environment/pdf/lcco2guideline.pdf (in Japanes)

[3] JIS (Japanese Industrial Standards) D4230 Automobile Tyres

[4] MAZDA MOTOR CORPORATION, Environmental Management, Initiatives in LCA. Available (2014-11-18) from: http://www.mazda.co.jp/csr/environment/management/lca_measures.html

[5] HINO Motors LTD., Environmental Performance, Environmental Load Reduction Activities Based on Life Cycle Assessment (LCA). Available (2014-11-19) from: http://www.hino-global.com/csr/environment/activity/lca.html

12. Appendices

Results from the critical review

The recommendations from the panel to the study are follows;

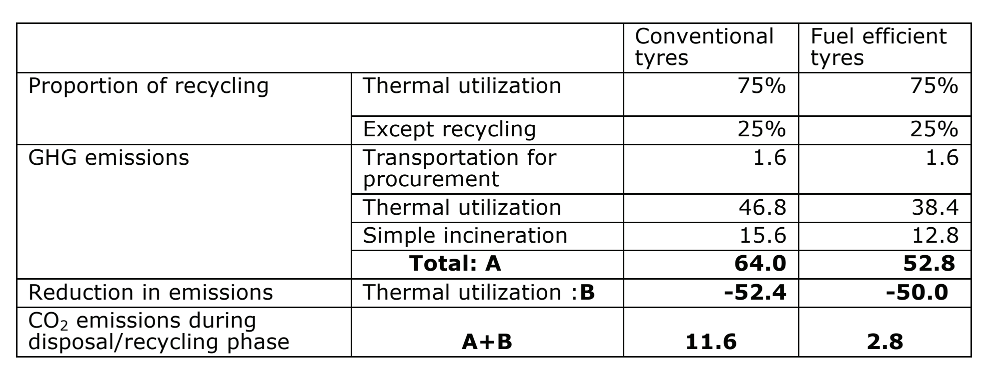
1. With regard to CO_2e emissions during the stage of disposal/recycling of tires for PCR, the details of the below figures of emissions from fuel efficient tires and the ones from conventional tires is expected to explain.-conventional tires: 2.9 kg CO_2e/tire-fuel efficient tires: 0.7 kg CO_2e/tire
2. The case study is expected to explain the settings of the market size of fuel efficient tires in 2020. It is desirable that the scenario be described in an easy-to-understand way.

The JCIA response to the above recommendations is follows;

1. The details of CO_2e emissions during the stage of disposal/recycling were shown by Table 4.
2. Regarding to market size of fuel efficient tires in 2020, corrections have been made to the explanations concerning the quantity of fuel efficient tires expected to be sold annually in 2020.

TABLE 4 - GHG EMISSIONS AND THE REDUCTION IN EMISSIONS DURING THE STAGE OF DISPOSAL/RECYCLING

(UNIT: KGCO_2e/ PCR, HAVING 4 TIRES)



		Conventional tyres	Fuel efficient tyres
Proportion of recycling	Thermal utilization	75%	75%
	Except recycling	25%	25%
GHG emissions	Transportation for procurement	1.6	1.6
	Thermal utilization	46.8	38.4
	Simple incineration	15.6	12.8
	Total: A	**64.0**	**52.8**
Reduction in emissions	Thermal utilization :**B**	**-52.4**	**-50.0**
CO_2 emissions during disposal/recycling phase	**A+B**	**11.6**	**2.8**

Driving condition in Japan

- average of running distance in one month in Japan : 450km>>>5400km in a year as of year of 2005 Available (2015-05-20) from:http://www.jama.or.jp/lib/jamareport/100/03.html Japan Automobile Manufactures Association Inc. JAMA Report No.100
- average of running distance at the time of automobile safety inspection (the first inspection for 3 years and later on for two years) for a private car: 10575km as of year of 2004, the report of The Minister of Land, Infrastructure, Transport and Tourism

Case 7 Multilayer Polyethylene packaging films

SABIC

COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned by Saudi Basic Industries Corporation (SABIC) and was performed by Rajesh Mehta, SABIC.

1. Purpose of the study

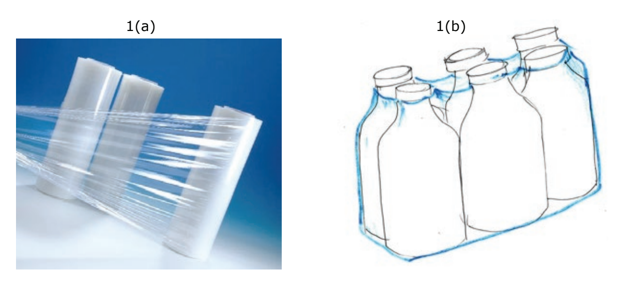
This study is conducted to provide a case study on "A Comparative Lifecycle Assessment on Multilayer Polyethylene Packaging Films" in alignment with the requirements of the document "Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies," developed by ICCA and the Chemical Sector Group of the WBCSD.

The objective of the study is to calculate the reduction in greenhouse gas (GHG) emissions during life cycle of a five layered packaging film as compared to the conventional three layered packaging film. This study, at a chemical product level, compares two multi-layered polyethylene (PE) packaging film solutions of 1000 square meter film area each. These films are marketed and consumed in Europe.

Packaging is required to protect the intended product from damage. Companies and consumers are moving towards sustainable packaging solutions by lower amounts of raw materials, reducing costs and developing additional packaging functionalities. Incorporating sustainability in packaging materials involves reducing the amount of material used by decreasing the wall thickness, changing the design of the package, using recycled material etc. However such solutions may not always result in providing a good protection to the products.

SABIC has developed a recipe for multilayer PE packaging film, which enhances material properties of the film and improves its material effectiveness allowing 22% reduction in film thickness[1-4]. SABIC's five layer packaging film matches the three layer reference film specification with respect to shrink force, optical and tensile properties but is 22% lighter in weight for equivalent functional unit basis i.e. 1000 m2 of film area[1-4]. In this work, we conducted lifecycle analysis of polyethylene (PE) multilayer packaging film used for packaging of a set of six bottle beverage pack, Figure 1.

FIGURE 1 - 1(a) MULTILAYER POLYETHYLENE PACKAGING FILM, 1(b) PACKAGING OF PACK OF SIX BEVERAGE BOTTLE WITH MULTILAYER PE PACKAGING FILM



2. Solutions to compare

2.1. Description of the solutions to compare

The focus of this study is a comparative cradle to end of life (EOL) lifecycle assessment of SABIC five layer film comprising of 35 microns film thickness with conventional three layer packaging film comprising of 45 microns film thickness. This study is conducted for collation shrink packaging for a set of six beverage bottles.

Globally, different materials such as paper, corrugated board and cardboard, plastic, aluminium, tinplate etc. are used for packaging of products. But for flexible packaging market, plastics packaging constituted more than 80% of the market share in 2011. Within plastics flexible packaging market sector, collation shrink film application is a sub-category. The present LCA study is conducted specifically on this collation shrink film application. In 2011, collation shrink film packaging was 31% of the plastics flexible packaging market.

Over the last couple of decades, use of multilayer concepts in flexible packaging film has increased as compared to monolayer films. Three-layer flexible packaging film became commercially available in late 90s and since then, have increased their market share for packaging film applications and hence three layer solution is selected as market incumbent for the PE packaging film application.

The five layer film results in packaging having excellent sealing properties in combination with excellent resistance to puncture, tear propagation, creep and expansion pressures. About 22% reduction in thickness for the five layer film, as compared to three layer film, is achieved by controlling the amount as well as specification of polyethylene in each of the five layer. Further, versatility of five layers extrusion setup allows the use of different types of raw materials in an efficient combination. The total thickness of the film depends on the packaging size and on the content of the packaging. For example, the thickness of the five layer film used for packing diapers may range between 20 and 60 micrometers. Generally thin film is applied for the package or bag with the lowest content of diapers and the thickest film is applied for the package with the highest amount of diapers.

Each packaging film is made up of three different polymer types, namely linear low density polyethylene (LLDPE), high density polyethylene (HDPE), low density polyethylene (LDPE). Figure 2, shows a layer wise structure of the two films. mLLDPE (Mettalocine-LLDPE) in three layer film is replaced by C4-LLDPE (butane-LLDPE) in five layer film. Figure 3, shows kilograms per functional unit of different polyethylene types in respective solutions[2,3].

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FIGURE 2 - CONVENTIONAL THREE LAYER PACKAGING FILM (45 µM) VERSUS SABIC FIVE LAYER PACKAGING FILM (35 µM)

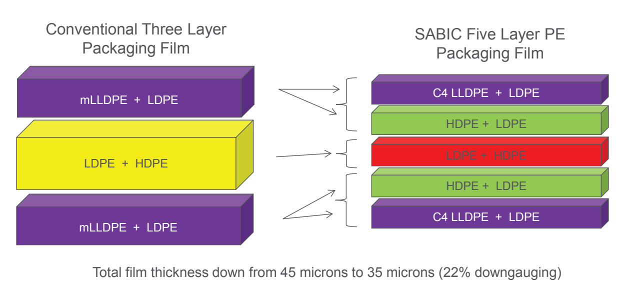
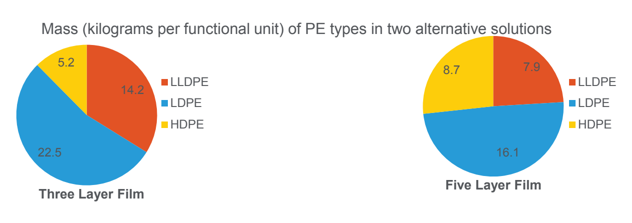


FIGURE 3 - MASS (KILOGRAMS PER FUNCTIONAL UNIT) OF PE TYPES IN TWO ALTERNATIVE SOLUTIONS- THREE LAYER FILM AND FIVE LAYER FILM



2.2. Level in the Value Chain

This study focuses on chemical product level and measure the reduction in emissions generated by five layer packaging film as compared to conventional three layer packaging film.

2.3. Definition of the boundaries of the market and the application

The study compares two alternatives for packaging of a set of six beverage or water bottles that have a capacity of 1.5 litres each and are manufactured and sold in Europe. The differences between the two alternatives i.e. the five layer PE film and the conventional three layer film are considered in this analysis. The focus of this study is a full cradle to end of life (EOL) lifecycle assessment. Use phase, including transportation, is not considered as it is assumed to be identical for both product systems. Both solutions provide same functionality, and the consumers do not feel any difference. Production of beverage bottles, beverage, and related transport are out of the system boundaries and are omitted since they are out of scope.

Energy demand for wrapping of packaging film for a set of six beverage bottles is minor compared to other unit operations and lifecycle stages. Hence the wrapping process is excluded in this study. Since one of the aims of the study was to generate credible LCA results within reasonable time, small errors in lifecycle footprint calculation resulting due to omission of wrapping process can be justified. Therefore, during the goal and scope discussion meetings it was decided to include most material lifecycle stages and processes impacting the lifecycle GHG emissions of PE packaging film.

The quantity of polymer grades sold by SABIC in Europe in 2012 for multilayer PE packaging film application is confidential and not reported. Therefore, for calculating total avoided emissions potential of five layer solution, present study relied on estimated volumes of collation shrink film application for European market. AMI consulting indicates that the specific application of collation shrink in Europe represented 0.95546 million tons in 2012.[5]

3. Functional unit and reference flow

3.1. Functional unit

Function

Primary role of packaging is to prevent the product from getting damaged during transporting, storing, handling, shelving, preservation, opening and usage in to account. In this study, multilayer PE packaging films is considered for applications such as six bottles water packs, beer cans pack, beverage collation shrink film.

Use of multilayer PE film in packing six bottles of water pack or beverage pack (Figure 1(b)) is specifically considered for this lifecycle study.

Functional unit of the product

The functional unit for this study is 1000 square meters of multilayer PE collation shrink packaging film for packaging of set of six beverage bottles of 1.5 litres each.

The functional unit has been selected taking into account the fact that the intended use and performance of both the multilayer films are identical.

Quality Requirements

The two alternative solutions considered in the study have different film thicknesses, 45 microns and 35 microns thickness respectively, yet both fulfil the same function, protecting and transporting of a set of six beverage bottles of 1.5 litres each. The two packaging films have same key product properties namely puncture and tear propagation resistance, optical properties, and shrink force.

Service Life

The service life of the packaging film is set by the expiry date of the product packed, considering the fact that the product was not opened. Service life of these films comprise of beverage pack at manufacturing site, transport of the packaged product to retailers, storage, and sale of final product. Service life of packaging film is same for SABIC's five layer solution and conventional three layer solution. Both films are produced, marketed and consumed in Europe. Reference year for comparison is year 2012.

3.2. Reference flow

Table 1 shows the reference flow, which is the amount of product necessary per functional unit for each product system. The reference flow is mass of each polyolefin type, grade, required per 1000 m^2 of packaging film. As mentioned in earlier, thickness of the three layer film is 45 microns where as that of SABIC's five layer film is 35 microns.

4. Boundary setting

Figure 4 shows the entire life cycle of multilayer PE packaging film. The system boundary consists of following four elements -

1. Production of Polyethylene:
   This process consists not only of production of polyethylene from ethylene, but also production of all upstream raw materials and transportation or distribution of raw material from cradle to polyethylene manufacturer gate. The PE packaging film is made up of 100% virgin polyethylene grades.
2. Processing:
   Blown Film Extrusion process is considered.
3. Distribution:
   Standard transportation distances are assumed for this step. Distribution of polymer grades to converter sites is considered. Transportation distance between the film producer, i.e. converter, and beverage manufacturer is excluded since the film will be produced in the local market, within a 250 km radius.
4. Disposal/recycling of PE packaging film:
   Landfill and incineration of PE packaging film and recycling of PE packaging film are considered. For the amount of PE material that is recycled into second life, 50:50 allocation method is used for sharing of production and recycling burdens between first and second life.

The product system includes the following life cycle stages:

- Raw material extraction
- Material processing
- Product manufacturing
- Final Disposal/ End of Life (EOL)

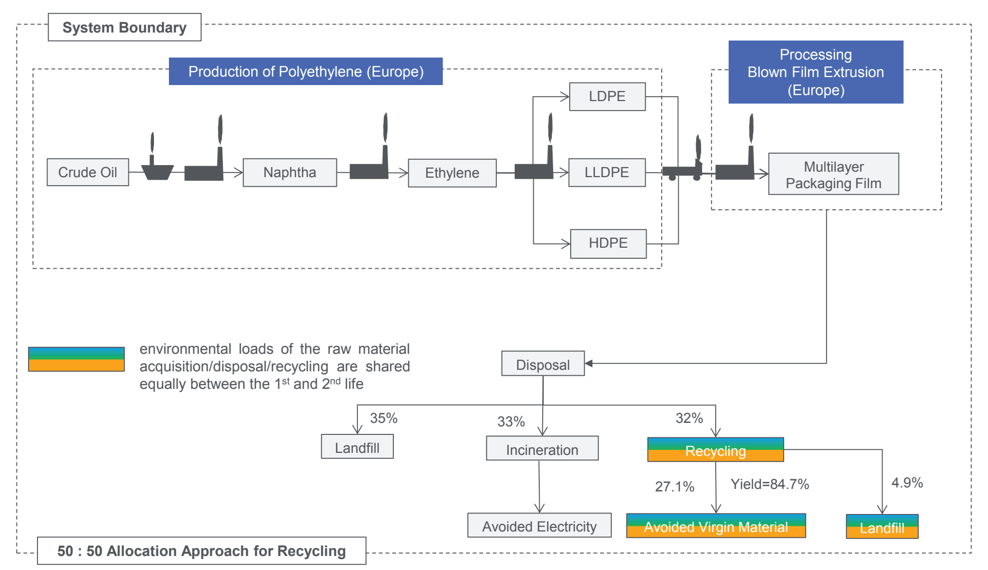
Use phase of the film is outside the system boundary. Use phase of the film comprises of beverage packaging at manufacturing site, transport of the packaged product to retailers, storage, sale, and finally consumption of packaged product.

Packaging of six bottles pack with five layer film and those of conventional three layer film are considered to have same process of production, use, disposal, and recycling. There are differences in the film thicknesses and structure of the two films, Table 1.

TABLE 1 - REFERENCE FLOWS PER FUNCTIONAL UNIT (1000 M^2)

Polyolefin Type	Reporting company's solution Five Layer collation Shrink Film (35 microns) kg/functional unit	Solution to compare to Three Layer Collation Shrink Film (45 microns) kg/functional unit
LDPE	7.9	14.2
LLDPE	16.1	22.5
HDPE	8.7	5.2
Total	32.7	41.9

FIGURE 4 - SYSTEM BOUNDARY FOR MULTILAYER PACKAGING FILM LIFECYCLE



EU 2010 recycling rates for plastics packaging. Source EOL Statistics : PlasticsEurope Report "Plastics- the Facts 2011"

5. Calculation methodology and data

5.1. Methods and formulas used

This study is conducted in accordance with guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies, developed by ICCA and the Chemical Sector Group of the WBCSD.

To clearly differentiate GHG avoidance resulting from the present innovation, this study assumes that there is no difference in manufacturing of virgin HDPE, LDPE, LLDPE that is used in five layer as well as the film three layer film. Therefore, the study uses industry average dataset to model production of virgin plastics in Europe i.e Ecoprofilies from PlasticsEurope.[6-8] Comparison of difference in SABIC product and supply chain footprint, cradle to gate, versus industry average footprint is out of scope of the study. The comparison is at chemical product level innovation by developing a better recipe to achieve 22% thinner films with same type of polymer types.

All the background data were selected from the Ecoinvent version 2 dataset available in SimaPro version 7.3.3.[8-14,16]

For the two product systems compared, it is assumed that there is no major difference in specific energy consumption for blown film extrusion process due to change in number of layers, material or grades. Justification for this assumption is that all of the grades considered are PE types and are co-extruded.

For recycling processes, lifecycle inventory dataset from Franklin associates for collection, sorting and production of recycled HDPE pellet were used and adapted for Europe geography[17]. Data reported on mass, energy, fuel consumption, transportation type and distance was used to build recycled HDPE model in SimaPro 7.3.3. Adaptation of the recycling processes from US geography to Europe geography was done by using Europe specific Ecoinvent background datasets. Major assumptions applied for this adaptation is that collection, sorting, production of recycled HDPE processes are similar in two geographies.

5.2. Allocation

Some amount of postconsumer multilayer PE film is recycled into second life and used for replacing virgin PE in other low end applications. For the amount of PE film that is recycled back into second life, 50:50 allocation method is used for allocating virgin material production burden and recycling burdens between first and second lives. This rule is commonly accepted as a "fair" split between two coupled systems.

Every one kg of recycled plastic does not replace equivalent amount of virgin plastic due to material losses in the recycling process and inferior material properties of recycled plastic. Reported data from Franklin Associates on recycling yield, 84.7%, was used.

As material properties of recycled plastic are inferior to virgin plastic, a higher amount of recycled plastic is required to replace virgin plastic to meet the same functionality.[18,19] This study uses data reported by UK's Waste & Resources Action Programme (WRAP) in its LCA study on milk packaging systems.[19] According to the WRAP report, for an open loop recycling, 1 kg of recycled HDPE replaces 0.825 kg virgin HDPE due to material property requirements. Therefore, after taking into account recycling yield and material property differences every 1 kg recycled plastic film will only replace 0.6988 kg of virgin PE. In 50:50 allocation approach, for the amount of PE recycled into second life, this translates into 65.06% virgin PE footprint taken up by first life and only 34.94% of virgin PE material footprint taken up by recycled PE.

Four different allocation approaches to recycling were applied to study the effect of allocation approach on packaging film's first life absolute footprint. For all allocation approaches, same recycling yield and material property degradation relationship between recycled and virgin PE is used. Results on sensitivity analysis are shown in section 7.

5.3. Data sources and data quality

PlasticsEurope's Eco-profiles datasets on LDPE, HDPE, LLDPE resins are used to calculate cradle to gate footprint of respective polymer resins[6-8]. Eco-profile datasets from PlasticsEurope are industry average datasets of European plastics manufacturers.

For blown film extrusion, Ecoinvent datasets is used. Comparison of energy consumption of blown film extrusion process was done with energy consumption data reported in other literature sources.[20,21] Average electricity consumption of film extrusion process reported by Ecoinvent is 0.66 kwh/kg of plastic film, which is consistent with data reported in reference[20] but 50% lower than industry average data reported in reference [21]. Ecoinvent film extrusion dataset was considered to be more representative as it had generated entire input and output data set for film extrusion after a comparison with APME and BUWAL reported input-output data.[9] Reference [21] reported high variance in energy consumption data due to age of machinery, utilization rates and other factors. SABIC product development and marketing experts also confirmed representativeness of Ecoinvent data based on their experience. It must be noted that it difficult to get primary data from individual converters due to confidentiality reasons. Having access to energy and bill of material data of blown film extrusion process provides direct access to converter's cost model, which is business sensitive information.

Further, Ecoinvent datasets on transportation, landfill, incineration and end of life scenario are used. [9-14] PlasticsEurope end of life statistics for Europe geography is used.[15] Primary data from SABIC's product development trials conducted in year 2011, has been used for the film design. Table 2, lists type of datasets used for building lifecycle stage or unit operation model. Information on temporal, geographical and technological coverage of datasets used is also provided.

TABLE 2 - LIFECYCLE INVENTORY DATASETS

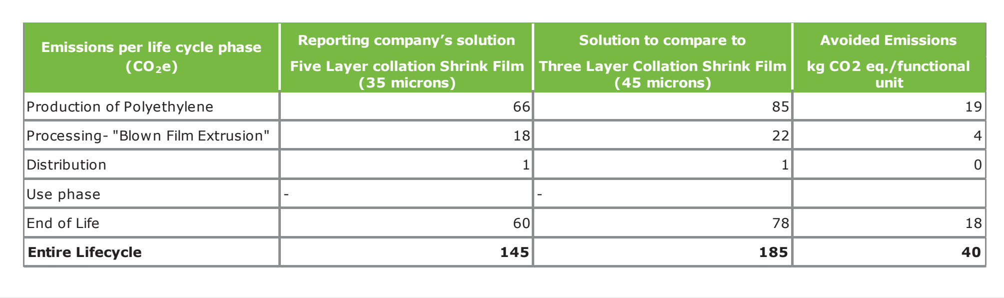
Lifecycle Stage or Unit Operation	Temporal Information	Geographical Coverage	Technological Coverage	Type of Dataset Used	Reference
Resin Production- Virgin HDPE resin	European industry average data of the year 1999-2001.	Based on European average production (24 production sites)	The most representative Technologies	Industry average data	Ecoinvent life cycle inventory adapted from PlasticsEurope Eco-profiles. Ecoinvent Report # 11
Resin Production- Virgin LDPE resin	European industry average data of the year 1999-2001.	Based on European average production (27 production sites)	The most representative Technologies	Industry average data	Ecoinvent life cycle inventory adapted from PlasticsEurope Eco-profiles. Ecoinvent Report # 11
Resin Production- Virgin LLDPE resin	European industry average data of the year 1999-2011.	Based on European average production (8 production sites)	The most representative Technologies	Industry average data	Ecoinvent life cycle inventory adapted from PlasticsEurope Eco-profiles. Ecoinvent Report # 11
Transport- resin to converter	2000	European average	Road transport - European fleet average – Truck	Industry average data, Lorry > 16 t	Ecoinvent Report 14_Transport, Ecoinvent V2.0 (2007)
Film Extrusion Process	1993-1997	European average reported by Ecoinvent	The most representative Technologies	Industry average data (Literature)	Reported Ecoinvent LCI dataset on blown film extrusion used. Ecoinvent Report 11_II_Plastics
Multilayer film recipe/thickness	2011	European	Product Specific	Actual Data	SABIC Recipe and SABIC reported material property data for PE grades used.
Use Phase	Excluded	NA	NA	NA	NA
Transport- End of Life	2000	European average	Road transport European fleet average – Truck	Industry average data	Ecoinvent Report 14_Transport, Ecoinvent V2.0 (2007)
End of Life- Management	2011	EU-27 2010 recycling rates for plastics packaging	2011 European Scenario	EU-27 average	PlasticsEurope Report “Plastics- the Facts 2011”
End of Life Models- Landfill, Incineration	2000	European average	The most representative Technologies	Literature	Ecoinvent Report # 13_I_Waste_treatment_General_V2.1 Ecoinvent Report 13_II_Waste_Incineration_V2.1 Ecoinvent Report 13_III_Landfills_V2.1
Recycled PE LCI	2011	US industry average adapted for European geography	The most representative technologies	Industry average data	Adapted from Franklin Associates LCI on recycled HDPE. All unit process datasets were adapted for Europe and European background datasets were used

6. Results

6.1. Avoided emissions

The main results for five layer PE film and three layer PE film for packaging of set of six beverage bottles are shown in Table 3.

TABLE 3 - THE AVOIDED CO_2e EMISSIONS PER 1000 M2 OF PACKAGING FILM (KG CO_2e/1000 M2 OF FILM)



Emissions per life cycle phase (CO_2e)	Reporting company's solution Five Layer collation Shrink Film (35 microns)	Solution to compare to Three Layer Collation Shrink Film (45 microns)	Avoided Emissions kg CO2 eq./functional unit
Production of Polyethylene	66	85	19
Processing- "Blown Film Extrusion"	18	22	4
Distribution	1	1	0
Use phase	-	-	
End of Life	60	78	18
Entire Lifecycle	**145**	**185**	**40**

The avoided emissions are calculated as the difference between the life cycle GHG emissions of five layer PE film and those with conventional three layer PE film.

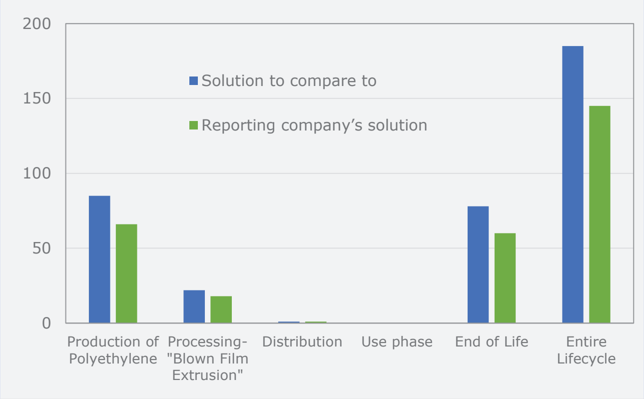
The results show that the avoided emissions per packaging film are dominated by the GHG emissions related to production of polyethylene, end of life disposal, and blown film extrusion process. The impact of distribution is small. Comparing the results of the two alternatives demonstrates that five layer PE packaging film has a 22% lower carbon footprint and thus reduces GHG emissions.

Five Layer Film Avoided Emissions Case

- Avoided CO_2e emissions per functional unit: 40 kg-CO_2e/functional unit
- Quantity of polymer grades sold by SABIC in Europe in 2012 for multilayer PE packaging film application is confidential and not reported. Therefore, total avoided emissions potential of five layer solution, was arrived using estimated volumes of collation shrink film application for European market. Hence, total avoided CO_2e emissions potential for European collation shrink film market, 0.95546 million tons in 2012, is calculated to be 1.168 million tons CO_2e.

Figure 5, shows comparison of lifecycle GHG emissions for SABIC five layer PE film versus conventional three layer PE film for the studied application. Clearly, five layer film has better environmental performance compared to three layer film in all lifecycle stages. It must be noted that use phase is outside system boundary in the present study.

FIGURE 5 - LIFECYCLE GHG EMISSIONS OF FIVE LAYER PE PACKAGING FILM, AND CONVENTIONAL THREE LAYER PACKAGING FILM



As mentioned in section 5.2, sensitivity studies were carried out to understand impact of different allocation approaches to recycling on packaging film's first life absolute footprint. The four studied allocation approaches are namely cut-off, 50:50 allocation, open loop recycling and avoided burden allocation approach.

Cradle to EOL lifecycle impacts were smallest when avoided burden allocation approach was applied, followed by 50/50 and open loop. Cut off approach showed highest environmental footprint for PE packaging film. Table 4 shows results from the sensitivity studies. Although type of allocation approach used, impacted total avoided emissions, overall conclusion of the study does not change.

TABLE 4 - COMPARISON OF RECYCLING ALLOCATION APPROACHES

Allocation Approach Used	Reporting company's solution Five Layer collation Shrink Film (35 microns)	Solution to compare to Three Layer Collation Shrink Film (45 microns)	Avoided Emissions kg CO2 eq./functional unit
Cut-Off Approach	153	196	43
50:50 Allocation	145	185	40
Open Loop Allocation	152	195	42
Avoided Burden	136	174	38

Further, sensitivity studies were also performed to measure effect of higher recycling rates; increase in 10% recycling rate reduced the lifecycle GHG emissions by 4.4%.

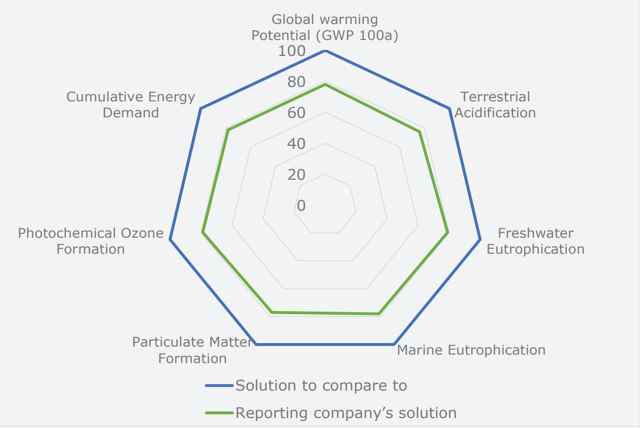
In the goal and scope of the studied it was decided to evaluate seven environmental impact categories to ensure that there are no trade-offs or negative environmental impacts in any of the impact categories. Table 5 below lists all studied impact categories and respective impact assessment methods that are used.

TABLE 5 - SEVEN ENVIRONMENTAL IMPACT CATEGORIES THAT ARE STUDIED

Impact category	Unit	Impact Assessment Method
Global warming (GWP100)	kg CO2 eq	IPCC 2007 GWP 100a
Terrestrial acidification	kg SO_2 eq	ReCiPe Midpoint (H) V1.05 / World ReCiPe H
Freshwater eutrophication	kg P eq	
Marine eutrophication	kg N eq	
Particulate matter formation	kg PM10 eq	
Photochemical ozone formation	kg NMVOC eq	
Cumulative Energy Demand	MJ surplus	Cumulative Energy Demand V1.08

On a lifecycle comparison basis, it was observed that SABIC five layer film has lower environmental impacts for all studied impact categories compared to three layer film. Depending on impact category, environmental performance of SABIC five layer film was 20-24% better.

FIGURE 6 - COMPARATIVE ASSESSMENT OF ALL STUDIED ENVIRONMENTAL IMPACT CATEGORIES (AS A PERCENTAGE)



6.2. Scenario analysis

No scenario analysis on future developments is performed in this study.

7. Significance of contribution

The chemical products addressed in this study, namely different types of polyethylene grades, make fundamental contribution to reduced GHG emissions. Innovation in this specific case is realized by product design based on right combination of polymer resins and number of layers rather than new enhanced resins. The substances are key components of PE packaging film that reduce material use in packaging application.

The calculated avoided emissions are not attributed to individual value chain partners.

8. Review of results

In September 2013, the study was presented to in Indian Life Cycle Management conference.[22] The scientific committee reviewed the abstract and presentation, however conference scientific committee review does not fall under an LCA peer review, which is described in ISO14044.[23,24] The review only focused on the methodology employed to conduct comparative lifecycle assessment.

9. Study limitations and future recommendations

Total avoided emissions for collation shrink film application is mainly influenced by the type of application and resulting reduction in film thickness for studied application. SABIC PE grades for five layer collation shrink film application are supplied for other packaging applications namely diaper compression packaging, and packaging of insulation materials, rockwool, foams, textile articles and waste. Actual reduction in film thickness achieved for specific application may be different compared to packaging of set of beverage pack.

Another limitation of the study is assumptions around recycling. In general, packaging films are difficult to recycle due to their large volume to mass ratio and lack of recycling infrastructure. This study assumes that Europe recycling statistics on plastics packaging is valid for multilayer packaging films. However, overall conclusion that SABIC five multilayer film result in 22% reduction in GHG emissions compared to conventional three layer film does not change. This was validated through sensitivity study assuming 50% landfill and 50% incineration scenario for EOL.

The study compares chemical product level innovation having a better recipe to achieve 22% thinner films with same type of polymer types. Therefore, comparison of difference in SABIC cradle to gate supply chain footprint versus industry average footprint is out of scope of the study. Use of industry average data is the third limitation of the study considering the fact that there are differences in production processes, transportation, and upstream supply chain of individual chemical manufacturers of LDPE, HDPE, and LLDPE. Inclusion of specific supply chain data will eliminate this limitation, and help improve the study further.

Another limitation of the study is use of old LCI datasets in the absence of non-availability of latest LCI data. Considering that chemical industry and its value chain continuously strives for improving its energy efficiency, reducing waste, and optimizing supply chain, it is expected that use of slightly older LCI datasets will result in minor over estimation of GHG footprint and avoided emissions.

10. Conclusions

Results from the study show that 22% reduction in film thickness of the packaging film results in close to 22% reduction in lifecycle greenhouse gas emissions. Every 1000 m^2 of five layer PE film result in 40 kg of avoided GHG emissions compared to conventional three layer film (50/50 Allocation Approach). We concluded that increase in material effectiveness through product innovations has a linear impact in reduction of environmental footprint of this specific PE packaging film case.

11. References

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Case 8 Engineering plastics for vehicle light-weighting

Solvay

COMMISSIONER AND PERFORMER OF THE STUDY

The study has been commissioned by Solvay Engineering Plastics and has been performed by Solvay Research & Innovation (Jean-François VIOT).

1. Purpose of the study

The objective of the study is to illustrate the potential of light-weight car parts in designing increasingly fuel-efficient cars in all car segments (small and medium size, large cars). The study focusses on a particular car model for which a car part made of engineered plastics has been designed and adopted by the car manufacturer for this specific model.

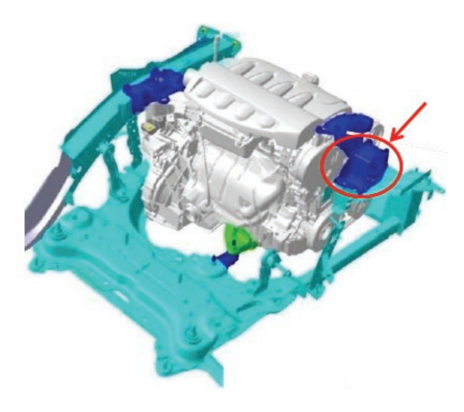
The study demonstrates the contribution of a single small car part, by calculating the reduction in greenhouse gas (GHG) emissions resulting from the use of an engineering plastic (Solvay's Technyl® A 218 V50 BLACK 21 N, named Technyl® in the report) instead of aluminium alloy (Al Si9 Cu3) as material for an automotive part: an **Engine Mount Housing** (see Figure 1) that provides the same service, during the same life span. The study encompasses the full life cycle of the two versions of that part, considering of course in particular their contributions to the automotive fuel consumption during its usage phase.

This study therefore consists of a comparison of GHG emissions occurring during the various life cycle steps:

- production of materials,
- manufacturing of the car part,
- use-phase of the car part,
- end of life of the car part,

for both solutions for the car part.

FIGURE 1 - VIEW OF THE ENGINE MOUNT HOUSING, A CONNECTING PART BETWEEN THE ENGINE AND THE VEHICLE STRUCTURE, IN ITS APPLICATION SURROUNDING (FROM [6])



This study is conducted in alignment with the requirements of the *"Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies"*, developed by the Chemical Sector Group of the WBCSD and ICCA.

The general context of this study is the reduction of fuel consumption and related CO_2 emissions for vehicles, and more particularly for passenger cars. Indeed, environmental regulations on vehicle emissions push automotive manufacturers to design and produce vehicles that consume less fuel while maintaining performance. To achieve this, the potential levers available to car manufacturers and their suppliers are manifold. One of these levers is vehicle weight reduction.

Progresses made in the combined fields of material performance and car parts design allow increasing access to lighter elements for identical functions, both in terms of initial performance and in terms of maintaining these performance during the lifetime of the vehicle.
For years now, replacing metal parts by engineering plastics has continuously increased, conquering car parts with high level specifications, such as "under the hood" elements.

Amongst recent successes is the "Engine Mount Housing" made of Technyl® instead of aluminium alloy, for a range of small and medium size cars.

This study reports the case example of Engine Mount Housings for a specific small-medium size car model (see characteristics below). For this new car, the Engine Mount Housing is made of Technyl®, instead of aluminium alloy. It is already known **[6]** that such a new design reduces the weight of the part by 30% as compared to the more traditional aluminium alloy part, substituted for this new model in order to reach the objectives of light-weighting. This study however endeavours to take all life cycle stages, not just the use phase, into account. To be noted that there is no environmental trade-off (other environmental negative effects that would impact the value of the solution) related to the low-carbon solution.

This study of a particular small car part also illustrates the past and future further weight gains achievable for a broad range of under-the-hood car parts, especially also in larger cars, where an even broader range of parts can still be further lightened (for example: weight reduction can go up to 40% in case of larger Engine Mount Housings equipping larger cars).

2. Solutions to compare

2.1. Description of the solutions to compare

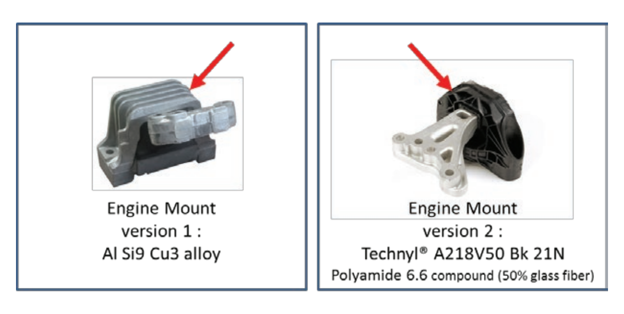
In line with the previous paragraph, the two versions of the Engine Mount Housing are defined as follows:

Version 1 (solution to compare, used in similar car models):
Material: Aluminium alloy Al Si9 Cu3,
Weight: 400 grams (corresponding to a weight gain of 30% between the two versions) manufactured by die casting,

Version 2 (solution of reporting company, equipping the new Peugeot 208):
Material: Technyl® A 218 V 50: a polyamide 6.6 compound (reinforced with 50% glass fibers) + metals inserts (steel: 11SMnPb30)
Weight: 280 grams:

- 236 grams Technyl® A 218 V50
- 44 grams steel 11SMnPb30
  manufactured by injection molding,

FIGURE 2 - ILLUSTRATION OF THE TWO VERSIONS OF THE STUDIED ENGINE MOUNT (ONLY PARTS INDICATED BY THE RED ARROWS ARE CONSIDERED)



Quantifying projections of the respective market shares of the 2 versions is most difficult, since substitution of metal by plastics for that car part is an ongoing process, which depends on car brands and even models within each brand. Parameters such as car size and motorization are essential and a relevant overall picture is today impossible to be drawn. However the trend is clearly towards significantly more plastic engine mount housings in the future for the sake of light-weighting, in many car models, thus with significant and growing market shares.

2.2. Level in the Value Chain

This study is conducted at the end-use level. It encompasses the entire life cycle of the automotive part considered as an example (Engine Mount Housing). CO_2 emissions are compared between the 2 solutions (Technyl® or aluminum alloy) during each life cycle step. In the usage step, the contribution of the part to the vehicle fuel consumption is considered through its contribution to the vehicle weight.

Definition of boundaries of the market and the application

Annual production of the considered car, equipped with Technyl®-based Engine Mount Housing, represents 280000 vechicle in 2014. It is produced in Europe.
The Engine Mount Housings are also manufactured in Europe.

- Aluminium alloy Al Si9 Cu3 is considered to be produced in Europe.
- Technyl® A218 V50 Black 21N is produced in Europe by Solvay.

3. Functional unit and reference flow

3.1. Functional unit

The function of an Engine Mount Housing is to ensure a point of attachment between the engine/gearbox set and the car body. There are three such points of attachment in this car (see Figure 1, parts highlighted in blue), different in shape and design. The Engine Mount Housing studied here is the one located at the upper side of the engine. The other two are located:

- One at the upper side of the gearbox,
- One at the lower side of the engine (essentially supporting the torque when the engine is running.

Both versions of the studied Engine Mount Housing bring exactly the same function. The Engine Mount Housing service life is equal, in both versions, to the service life of the car: Under regular operation, there is no need for replacement during the car life. All computations in the car industry are based on a life span of 150 000 km, for small cars. This value is thus adopted in this study.

The functional unit of the Engine Mount Housing is thus defined as:

To ensure one attachment point between the engine/gearbox set and the vehicle structure in a small-medium size car, throughout the vehicle's lifetime (150 000 km).

Car characteristics are:

- Empty weight: 975 kg
- Fuel (gasoline) consumption in mixed cycle (NEDC): 4,5 litres/100 km

No reuse of the part is considered since most unlikely to occur.

3.2. Reference flow

The reference flow is the mass of product necessary to manufacture one Engine Mount Housing:

- 400g for version 1;
- 280g for version 2.

Version 1 (solution to compare, used in similar car models)

- Material: Aluminium alloy Al Si9 Cu3 (ENAC 46000),
- Weight: 400 grammes
- 60% of the aluminium is originated from recycling (35% from new scraps, 25% from old scraps);
- 40% of the aluminium is primary.

manufactured by die casting.

Data for the Aluminium alloy model is based on Ecoinvent v2.2 datasets and on ENAC 46000 composition (Table 1).

Version 2 (solution of reporting company, equipping the new Peugeot 208)

- Material Technyl® A 218 V 50:
  - 50(-ε)% polyamide 6.6, 50% glass fiber,
  - -ε masterbatch
  - + metals inserts (steel: 11SMnPb30).
- Weight : 280 grams:
  - 236 gram Technyl® A 218 V50,
  - 44g steel 11SMnPb30.

  Manufactured by injection molding.

4. Boundary setting

The steps of the life cycle considered in both Versions are the following:

Production of materials: ingredients, intermediates and raw materials for manufacturing the car part,

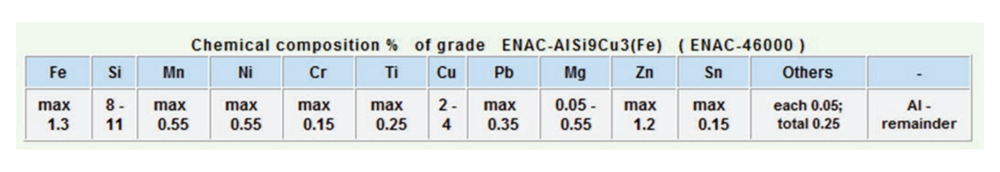
Manufacture of the car part: Technyl® A 218 V50 is produced in Europe by Solvay. A schematic process route is given at Figure 3.

Use of the car part: the contribution of the “Engine Mount Housing” to fuel consumption of the vehicle - this contribution is exclusively depending on the weight of this car part, that the vehicle carries throughout its life,

End of life of the car part: the dismantling step of the part is omitted, but end-of life is included

- For version 2 (Technyl®), no end-of-life recycling is actually in place ; in the absence of more precise data, the hypothesis of 50% incineration (with no energy recovery) and 50% landfilling has been adopted.
- For the aluminium version alloy it can be assumed that the Engine Mount Housing is fully recycled. However recycling operations for the Engine Mount Housing are outside the system boundary: in the EAA datasets for aluminium the benefits and burdens of recycling are attributed to the recycled material (according to scheme in Figure 4). As a consequence, in the present study, no GHG emission of the recycling process of aluminium alloy Engine Mount Housing should be added.

TABLE 1 – CHEMICAL COMPOSITION OF GRADE ENAC AISI9CU(FE) (ENAC 46000)



Chemical composition % of grade ENAC-AlSi9Cu3(Fe) (ENAC-46000)

Fe	Si	Mn	Ni	Cr	Ti	Cu	Pb	Mg	Zn	Sn	Others	-
max 1.3	8 - 11	max 0.55	max 0.55	max 0.15	max 0.25	2 - 4	max 0.35	0.05 - 0.55	max 1.2	max 0.15	each 0.05; total 0.25	Al - remainder

FIGURE 3 - SCHEMATIC MANUFACTURING FLOWCHART FOR SOLVAY’S TECHNYL® A 218 V50 BLACK 21N

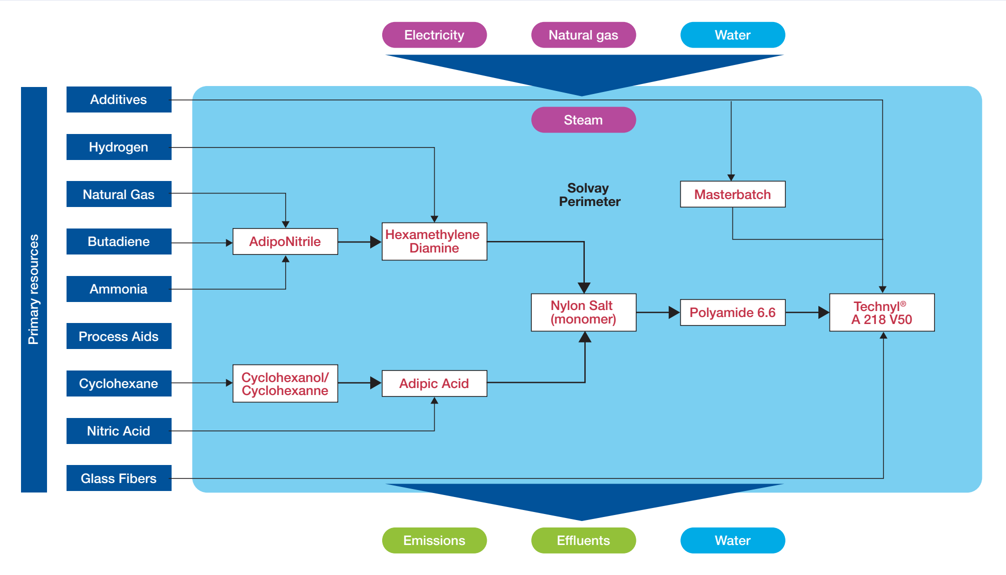
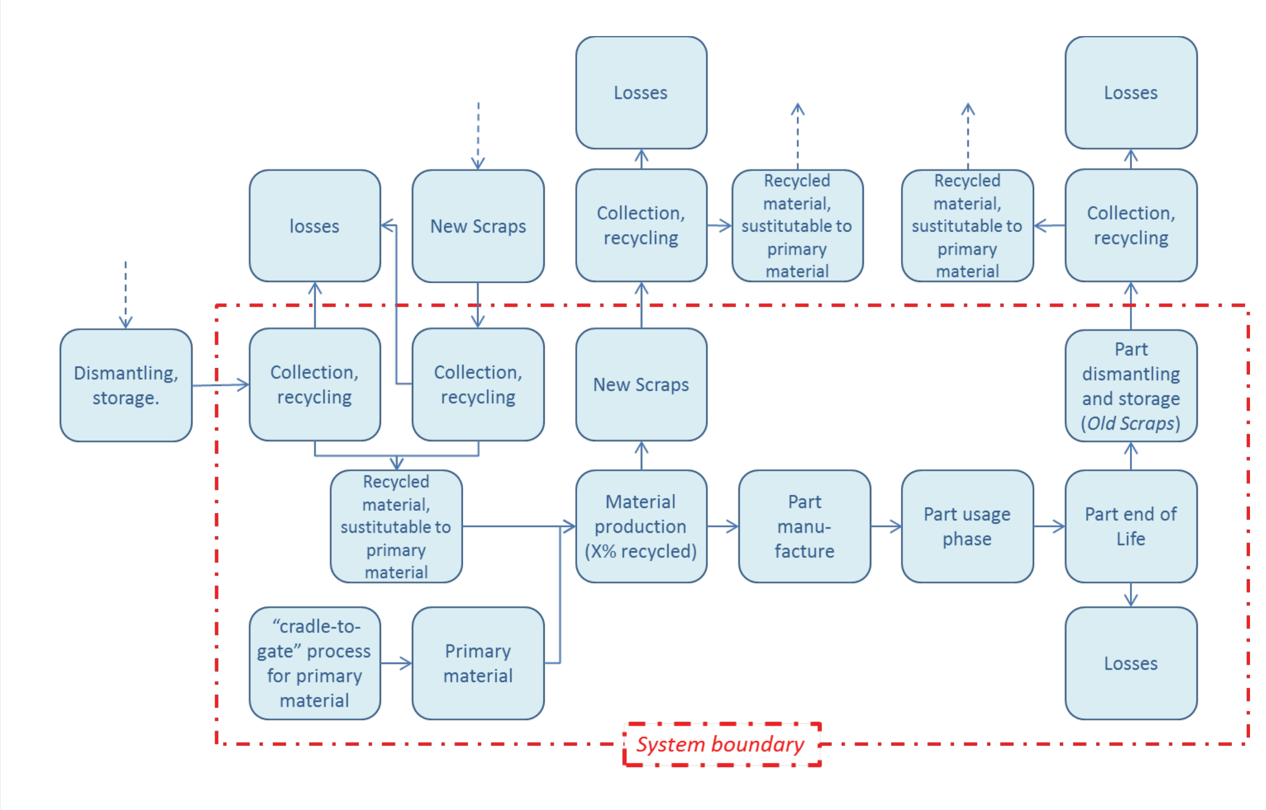


FIGURE 4 - SCHEMATIC REPRESENTATION OF THE SYSTEM BOUNDARIES FOR PARTLY RECYCLED ALUMINIUM



Note that:

- The production and maintenance of the car itself are identical for both solutions.
- The operations to place the part on the vehicle (mounting) are omitted, since equivalent for both solutions, and negligible anyway.
- Transport is not considered (excepted that included in background data) ; this is a conservative assumption since the transported quantities are globally higher in the case of the aluminium alloy Engine Mount Housing; moreover the distances are small as compared to the distance covered by the car (150 000 km) during its lifetime*.
- For the use phase, for both cases, only the weight of the part is taken into account.
- As often in Life Cycle Assessments of industrial products, the construction and the future demolition of manufacturing infrastructure equipment are not included in inventories.
- Car fuel consumption, apart from the Engine Mount Housing contribution, is outside the system boundary, since equal for both solutions.

5. Calculation methodology and data

Greenhouse Gas emissions are calculated using the latest IPCC 2013 100y set of GWP, as available in SIMAPRO 8.0.3.14.

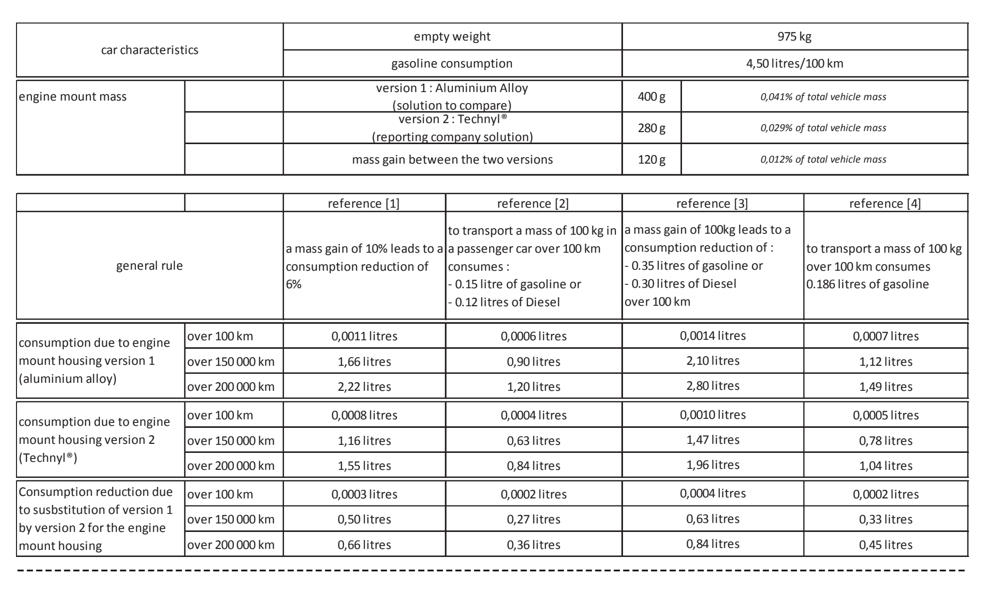
For the usage step, emissions consist in the contribution of the part to the car gasoline consumption. The Engine Mount Housing is a motionless part in the vehicle, that has no incidence on vehicle penetration into air (aerodynamics) and that does not participate to rolling resistance. Therefore it contributes to car gasoline consumption through its weight only.

Relationship between weight and vehicle consumption has been thoroughly studied. In the present study, recommendations from SAE (reference [1], see note below), presently most commonly used in the automotive industry were followed, i.e. a reduction by 10% of the overall weight of the car leads to a reduction in the car fuel consumption of 6%. This rule is considered to be linear, thus a gain of x% in the overall car weight leads to a reduction in the car fuel consumption of 0.6 x%.

Note: Table 2 below summarizes the output of each of those 4 references and their application to the present case study. Reference [1] is the SAE reference commonly used by car manufacturers. References [2] and [4] are among major papers. Reference [3] proposes a review and a synthesis of various papers.

* Usage phase of the Engine Mount Housing is equivalent to its transportation by a passenger car during 150 000 km

TABLE 2 - RECOMMENDATIONS FROM SAE (REFERENCE 1) AND OTHER MAJOR GUIDELINES ON THE RELATION BETWEEN WEIGHT GAIN AND FUEL CONSUMPTION IN PASSENGER CARS, APPLICATION TO THE PRESENT CASE STUDY



car characteristics		empty weight	975 kg	
		gasoline consumption	4,50 litres/100 km	
engine mount mass		version 1 : Aluminium Alloy (solution to compare)	400 g	*0,041% of total vehicle mass*
		version 2 : Technyl® (reporting company solution)	280 g	*0,029% of total vehicle mass*
		mass gain between the two versions	120 g	*0,012% of total vehicle mass*

		reference [1]	reference [2]	reference [3]	reference [4]
general rule		a mass gain of 10% leads to a consumption reduction of 6%	to transport a mass of 100 kg in a passenger car over 100 km consumes : - 0.15 litre of gasoline or - 0.12 litres of Diesel	a mass gain of 100kg leads to a consumption reduction of : - 0.35 litres of gasoline or - 0.30 litres of Diesel over 100 km	to transport a mass of 100 kg over 100 km consumes 0.186 litres of gasoline
consumption due to engine mount housing version 1 (aluminium alloy)	over 100 km	0,0011 litres	0,0006 litres	0,0014 litres	0,0007 litres
	over 150 000 km	1,66 litres	0,90 litres	2,10 litres	1,12 litres
	over 200 000 km	2,22 litres	1,20 litres	2,80 litres	1,49 litres
consumption due to engine mount housing version 2 (Technyl®)	over 100 km	0,0008 litres	0,0004 litres	0,0010 litres	0,0005 litres
	over 150 000 km	1,16 litres	0,63 litres	1,47 litres	0,78 litres
	over 200 000 km	1,55 litres	0,84 litres	1,96 litres	1,04 litres
Consumption reduction due to susbstitution of version 1 by version 2 for the engine mount housing	over 100 km	0,0003 litres	0,0002 litres	0,0004 litres	0,0002 litres
	over 150 000 km	0,50 litres	0,27 litres	0,63 litres	0,33 litres
	over 200 000 km	0,66 litres	0,36 litres	0,84 litres	0,45 litres

5.1. Methods and formulas used

Greenhouse Gas emissions are calculated using the latest IPCC 2013 100y set of GWP, as available in SIMAPRO 8.0.3.14.

The simplified method proposed in the ICCA guidance is used (consistently with both the system boundary and functional unit definition): this means that only the contribution of the Engine Mount Housing is considered. Excepted the material of that part, the cars in the two solutions considered here are fully identical. The change in the Engine Mount Housing material has neither incidence on the rest of the car design nor on its operation conditions.

5.2. Allocation

No allocation has been necessary while modelling the foreground data.

5.3. Data sources and data quality

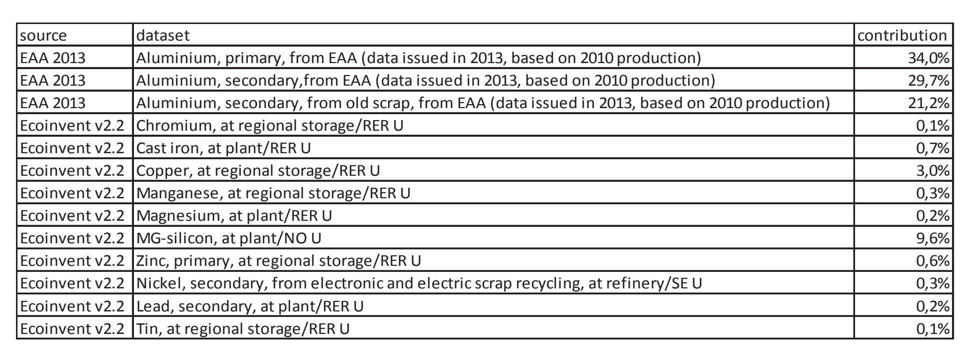
Material production and manufacture of the car part

Version 1 (solution to compare, used in similar car models)

- **Aluminium alloy** Al Si9 Cu3, which composition is given in Table 3, is modelled using :
  - Latest data from the European Aluminium Association for aluminium[5], issued in 2013 and based on data representative of year 2010 for :
  - Primary Aluminium used in Europe
  - Secondary Aluminium from new scraps (post-industrial scraps)
  - Secondary aluminium from old scraps (end-of-life wastes)

Ecoinvent V2.2 database for the other components of the alloy.

TABLE 2 - AL SI9 CU3 (ENAC 46000) MODEL IN THE PRESENT STUDY



source	dataset	contribution
EAA 2013	Aluminium, primary, from EAA (data issued in 2013, based on 2010 production)	34,0%
EAA 2013	Aluminium, secondary,from EAA (data issued in 2013, based on 2010 production)	29,7%
EAA 2013	Aluminium, secondary, from old scrap, from EAA (data issued in 2013, based on 2010 production)	21,2%
Ecoinvent v2.2	Chromium, at regional storage/RER U	0,1%
Ecoinvent v2.2	Cast iron, at plant/RER U	0,7%
Ecoinvent v2.2	Copper, at regional storage/RER U	3,0%
Ecoinvent v2.2	Manganese, at regional storage/RER U	0,3%
Ecoinvent v2.2	Magnesium, at plant/RER U	0,2%
Ecoinvent v2.2	MG-silicon, at plant/NO U	9,6%
Ecoinvent v2.2	Zinc, primary, at regional storage/RER U	0,6%
Ecoinvent v2.2	Nickel, secondary, from electronic and electric scrap recycling, at refinery/SE U	0,3%
Ecoinvent v2.2	Lead, secondary, at plant/RER U	0,2%
Ecoinvent v2.2	Tin, at regional storage/RER U	0,1%

- **Manufacture of the car part**
  For part manufacture, as data on Aluminium die casting are not available in Ecoinvent v2.2, it has been approximated by: “Casting, brass/CH U”.
  Such a proxy is justified by the very low contribution of that process step to CO_2 emissions over the entire life cycle.

Version 2 – (solution of reporting company, equipping the new Peugeot 208)

- **Polyamide 6.6 and Technyl® A 218 V50** models are based on primary data from Solvay’s production in Europe. A schematic process route is given at Figure 2. The dataset “Nylon 66, at plant/RER U” from Ecoinvent v2.2 are not used here because not representative anymore of the current industrial processes in place. Plastics Europe has issued a new ecoprofile for Polyamide 66 (or Nylon 66) in 2014, based on production data from 4 European Polyamide 66 producers (including Solvay). The overall reference year for this Eco-profile is 2011-2012. The primary data used here are those provided by Solvay to Plastics Europe for that ecoprofile update.
- **Glass fibers** are modeled by Ecoinvent v2.2 dataset : “Glass Fiber, at plant/RER U
- **Masterbatch** components are also modeled from Ecoinvent datasets.
- **Metal inserts** are modeled based on Ecoinvent v2.2 for both materials and processes:
  – “Steel, low-alloyed, at plant/RER U”
  – “Section bar rolling, steel/RER U”
  – “Turning, steel, conventional, primarily dressing/RER U”
  – “Zinc coating, pieces/RER U”
- **Manufacture of the car part**
  Part manufacture (injection moulding) is modeled with typical data provided by the industry, Ecoinvent v2.2 dataset “Injection moulding, RER/U”, being too far from the reality. Injection moulding data are confidential, obtained from the customer (plastics processing).

Use of the care part

GHG emissions attributed to gasoline consumption have been calculated from Ecoinvent v2.2:

- « Operation passenger car, petrol, EURO5/CH U », taking into account the sole emissions due to gasoline combustion, i.e. excluding emissions due to :
  - Tire wear
  - Brake wear

From that process, it can be calculated that the combustion of 1 litre of gasoline emits 2.85 kg CO_2 eq. of Greenhouse Gases. Those emissions include:

- Emissions during gasoline production and distribution
- Emissions due to gasoline combustion

It is thus a real “cradle-to-grave” inventory of GHG emissions during gasoline life cycle.

Namely, 2.33 kg CO_2 eq. are emitted during the combustion of 1 litre of gasoline while 0.52 kg CO_2 eq. are emitted during the production and distribution of 1 litre of gasoline. Gasoline losses by evaporation during the entire life cycle are included in the inventory of airborne emissions, but they have no effect on GHG emission since their GWP is equal to 0.

End of life of the car part

Version 1 – aluminium alloy (solution to compare)

As explained in section 4, recycling burdens and benefits of aluminium alloys are attributed to the recycled aluminium (from old scraps) included in the material used. No further emissions are considered at the end of life of the engine mount housing made of aluminium alloy.

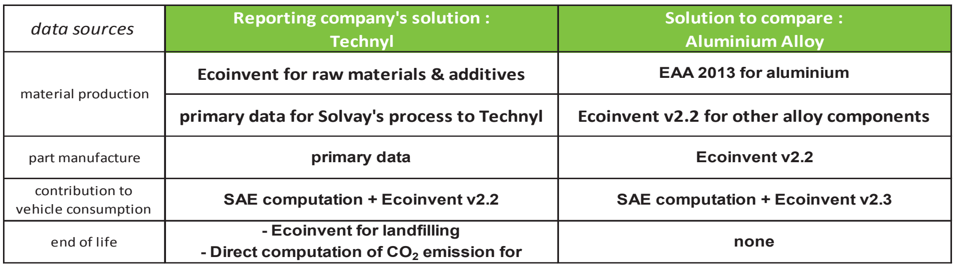
Version 2 – Technyl® (solution of the reporting company)

End-of-life is modeled as 50% landfilling, 50% incineration with no energy recovery.

- Landfilling is modeled by: Ecoinvent v2.2 “Disposal, polyurethane, 0.2% water to inert material landfill/CH U”, chosen as a representative proxy.
- Incineration is modeled by CO_2 emissions due to the organic part of Technyl® (50%), approximated as Polyamide 6.6. Polyamide 6.6 chemical formula is : $C_{12}H_{22}O_2N_2$, Mw = 226. The combustion of Polyamide thus leads to the emission of (12x44)/226 = 2.34 kg CO_2.
  Each Engine Mount Housing contains 236 grams of Technyl®, which corresponds to 118 grams of Polyamide 6.6, with the above hypothesis. Incineration of 50% of the engine mount housing at their end of life will correspond to the emission of 0.14 kg of CO_2 per Engine Mount Housing.

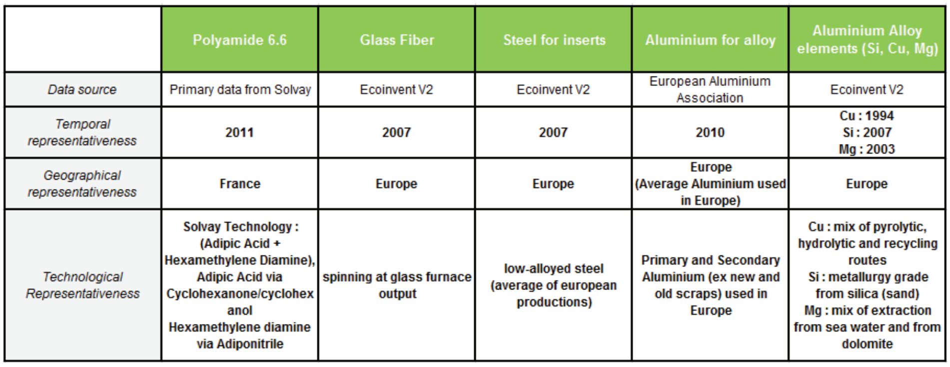
The sources of data are summarized in the following Tables:

TABLE 3 - SUMMARY OF DATA SOURCES USED FOR THIS STUDY



data sources	Reporting company's solution : Technyl	Solution to compare : Aluminium Alloy
material production	**Ecoinvent for raw materials & additives**	**EAA 2013 for aluminium**
	primary data for Solvay's process to Technyl	**Ecoinvent v2.2 for other alloy components**
part manufacture	**primary data**	**Ecoinvent v2.2**
contribution to vehicle consumption	**SAE computation + Ecoinvent v2.2**	**SAE computation + Ecoinvent v2.3**
end of life	**- Ecoinvent for landfilling - Direct computation of CO_2 emission for**	**none**

TABLE 5 - DATA SOURCES – ADDITIONAL INFORMATION



	Polyamide 6.6	Glass Fiber	Steel for inserts	Aluminium for alloy	Aluminium Alloy elements (Si, Cu, Mg)
Data source	Primary data from Solvay	Ecoinvent V2	Ecoinvent V2	European Aluminium Association	Ecoinvent V2
Temporal representativeness	**2011**	**2007**	**2007**	**2010**	**Cu : 1994 Si : 2007 Mg : 2003**
Geographical representativeness	**France**	**Europe**	**Europe**	**Europe (Average Aluminium used in Europe)**	**Europe**
Technological Representativeness	**Solvay Technology : (Adipic Acid + Hexamethylene Diamine), Adipic Acid via Cyclohexanone/cyclohexanol Hexamethylene diamine via Adiponitrile**	**spinning at glass furnace output**	**low-alloyed steel (average of european productions)**	**Primary and Secondary Aluminium (ex new and old scraps) used in Europe**	**Cu : mix of pyrolytic, hydrolytic and recycling routes Si : metallurgy grade from silica (sand) Mg : mix of extraction from sea water and from dolomite**

6. Results

6.1. Avoided emissions

GHG emissions during the entire life cycle of both solutions are summarized in Figure 5 as well as in Table 6, for one Engine Mount Housing.

FIGURE 5 - GRAPHIC VIEW OF AVOIDED EMISSIONS AND THEIR DISTRIBUTION OVER THE LIFE CYCLE OF THE ENGINE MOUNT HOUSING

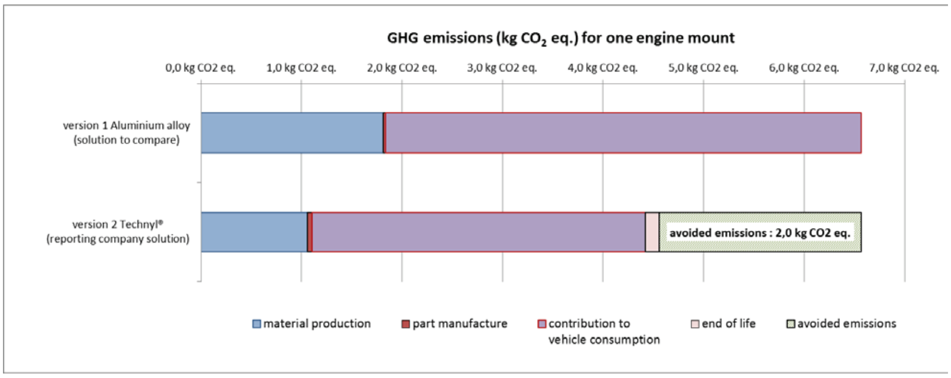
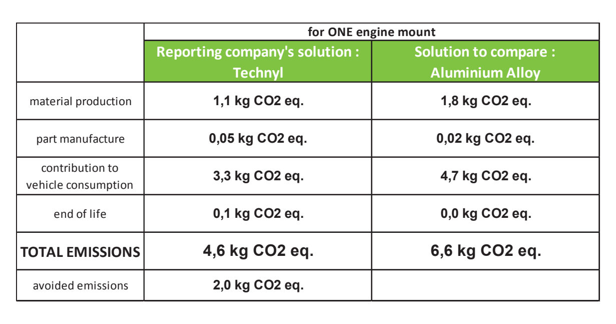


TABLE 6 - AVOIDED EMISSIONS OVER THE ENTIRE LIFE CYCLE OF THE ENGINE MOUNT HOUSING (ACCORDING TO REFERENCE [2] RECOMMENDATIONS FOR THE RELATIONSHIP BETWEEN CAR WEIGHT REDUCTION AND CAR FUEL CONSUMPTION



	for ONE engine mount	
	Reporting company's solution : Technyl	Solution to compare : Aluminium Alloy
material production	1,1 kg CO2 eq.	1,8 kg CO2 eq.
part manufacture	0,05 kg CO2 eq.	0,02 kg CO2 eq.
contribution to vehicle consumption	3,3 kg CO2 eq.	4,7 kg CO2 eq.
end of life	0,1 kg CO2 eq.	0,0 kg CO2 eq.
TOTAL EMISSIONS	4,6 kg CO2 eq.	6,6 kg CO2 eq.
avoided emissions	2,0 kg CO2 eq.	

The GHG emissions throughout the life cycle for one Engine Mount Housing are:

- 4.6 kg CO_2eq. for an Engine Mount Housing made of Solvay's Technyl®
- 6.6 kg CO_2eq. for an engine mount made of aluminium alloy Al SI9 Cu3

For the entire life cycle, the avoided emissions due to the choice of Technyl® instead of aluminium alloy as the material for the Engine Mount Housing in the defined car thus amount to 2.0 kg CO_2eq.

For the annual production of 280 000 vehicles/year, those avoided emissions sum up to 560 t CO_2eq.

It is realistic to consider that the car model considered will be produced over a ten year period. Thus deciding to use Technyl®, instead of aluminium alloy would save up to 5600 t CO_2eq. over the entire production of the car. Of course further improvements in car efficiency should be taken into account in such a calculation. However, although car fuel efficiency will in general, improve in the coming 10 years considered, this should have very little incidence on the calculated avoided emissions of this case study since : (1) the car model considered is equipped with a fairly recent engine type, which will very probably not be changed on this car model in the years to come or even on the whole production of this specific car model; (2) if an engine substitution / improvement would nevertheless take place that would increase the fuel efficiency of the car, thus also of transporting the considered car part, it would be relatively marginal, inducing only slight changes in the calculated avoided emissions.

Sensitivity to assumptions on relationship between car weight and fuel consumption

The rule used for the relationship between car weight reduction and reduction in car fuel consumption, explained under §5 ("a gain of X% in the overall car weight leads to a reduction in the car fuel consumption of 0.6 X %") is a major hypothesis in this study. On-going and future improvements in engine efficiency might impact that rule. No information is available to propose a more relevant rule for the car considered. If recommendations of reference [2] (which lead to the lowest benefit in car fuel consumption for a given weight reduction) would be followed, instead of those of reference [1], th is would lead to avoided emissions of 3920t CO_2 eq. (instead of 5600) over the entire production the car.

6.2. Scenario analysis

For the annual production of 280 000 vehicles/year, those avoided emissions sum up to 560t CO_2eq.
It is realistic to consider that the car model considered will be produced over a ten year period. Thus deciding to use Technyl®, instead of aluminium alloy would save up to 5600 t CO_2eq. over the entire production of the car. Of course further improvements in car energy efficiency should in fact be taken into account in such a calculation. However, although car fuel efficiency will in general improve in the coming 10 years considered, this should have very little incidence on the calculated avoided emissions of this case study since: (1) the car model considered is equipped with a fairly recent engine type, which will very probably not be changed on this car model in the years to come or even during the whole production period of this specific car model; (2) if an engine substitution / improvement would nevertheless take place within these 10 years that would increase the fuel efficiency of the car, thus also of the transport of the considered car part, it would be relatively marginal, inducing only slight changes in the calculated avoided emissions.

7. Significance of contribution

At the level of the Engine Mount Housing, the contribution of the reporting company's solution in avoided emissions is **fundamental**.

At the level of the car, the gain weight –when substituting aluminium alloy by Technyl® for this specific car part - represents 0.012% of the total car weight. Then the contribution of the reporting company's solution to avoided emissions is **minor**.

However, this example has been chosen to illustrate, in a particular case, the substitution of aluminium by Technyl® in the automotive industry, leading to significant weight savings of the whole car. That process of substitution has begun many years ago and will continue for some years. It is a major – if not the most important - contributor to car light-weighting, in all model of cars, with a high potential remaining especially in large cars. The challenge is to keep the level of performances and duration of parts with higher and higher level of specifications.

As far as attribution to different actors in the value chain is concerned, the calculated avoided emissions are not attributed to individual value chain partners. The substitution of the aluminium-based solution by the Technyl®-based solution is the result of different innovations and progresses that are shared all over the value chain. It is more relevant to consider it as collective progress than to try to distribute it between several individual contributors.

8. Review of results

A full study – including the analysis of other environmental indicators, in order to have a true multi-criterial analysis, as required by ISO 14040 & ISO 14044 – has been presented to a panel of French experts in the field of LCA and materials, for a critical review. The final answer is expecting in July 2015. This more extended study demonstrates in particular that emissions not taken into account here (mounting, transport of car parts, etc… represent in both cases only a few percent of the total emissions considered for this car part, and that they are very similar for both solutions, and would if taken into account (but no significantly) be in favour of the plastic solution.

9. Study limitations and future recommendations

A point of attention for the validity of the study in the future is – as detailed in § 6 - the model for car mass/fuel consumption relationship for passenger vehicles. That relationship is sensitive to engine and powertrain efficiency which are expected to further improve in the coming years. A follow-up of those model evolutions and possible updating of the calculations have to be planned.

10. Conclusions

The avoided emissions are presented as the difference of GHG emissions between an aluminium-alloy-based Engine Mount Housing and a Technyl® (glass fiber reinforced polyamide 6.6) Engine Mount Housing, over their entire life cycle. Both solutions equally fulfill all the requirements for ensuring a link point between the engine and the body of a small-middle size passenger car. When made out of Technyl®, this small car part ensures avoided emissions representing as much as 2.0 kg CO_2eq. per car during its entire life cycle as compared to the aluminium-alloy-based solution, equivalent to 5600 t CO_2eq. over the total production of that specific passenger car (estimated at 280 000 cars/year during 10 years). The major reason for this reduction is the lower weight of the polyamide 6.6-based version as compared to the Aluminium Alloy-based version, not only in the usage phase of the part (a lighter part to transport during the vehicle life span) but also in the production steps since less material needs to be produced and transformed.

Thus, the study demonstrates the potential of further gain in energy efficiency via the replacement of even small, under-the-hood, car parts by light-weight car parts.

11. References

[1] SAE Technical paper series # 982185 - EUCAR – Automotive LCA guidelines – Phase 2 (Dec 1998)
[2] On the calculation of fuel savings through lightweight design in automotive life cycle assessments, by Christoph Koffler & Klaus Rohde-Brandenburger, Int. J Life Cycle Assess (2010) 15 pp 128 – 135
[3] Energy savings by light-weighting Final report, by IFEU (a study commissioned by the Aluminium Institute, January 2003
[4] Life Cycle Assessment of Vehicle light-weighting : A physics-based model of mass-induced fuel consumption, by Hyung Chul Kim & Timothy J. Wallington, Env. Sci. Tecnol. (2013) 47, pp 14358 – 14366
[5] Environmental Profile Report for the European Aluminium Industry : Life Cycle Inventory data for aluminium production and transformation processes in Europe (data for the year 2010) European Aluminium Association, – April 2013
[6] Elastomer-Plastic Engine Mounts – Vibration Reduction and Lightweighting, presented by Trelleborg Vibracoustic at 17th Kunststoff- Motorbauteile Forum, Spitzingsee, Germany, Jan, 28th 2014.
[7] Eco-profiles and Environmental Product Declarations of the European Plastics Manufacturers : Polyamide 6.6 (PA6.6) ; PlasticsEurope ; February 2014, available at http://www.plasticseurope.org/

Case 9 Broiler production by feed additive DL-Methionine

Sumitomo Chemical

COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned and performed by Sumitomo Chemical Co., Ltd.

1. Purpose of the study

The objective of this study was to evaluate the reduction of greenhouse gas (GHG) emissions from broiler production in Japan using a chemically synthesized methionine product “DL-Methionine” as a feed additive. Livestock production is a major emitter of GHG. In particular, the emission of nitrous oxide (N_2O) from livestock manure management, which has a greenhouse effect around 300 times greater than carbon dioxide, accounts for 30% of the total GHG emissions from the agricultural sector in Japan[1].

One possible measure to achieve GHG reduction is to reduce the animal excretion of nitrogen, which is a source of N_2O emission in manure management. Reducing nitrogen content in feed supplemented with crystalline single amino acids is the most effective way of reducing nitrogen excretion.

As methionine is the first limiting amino acid in poultry feed, usage of DL-Methionine plays a key role in reducing the nitrogen content in broiler feed.

Thus, in this case study, the contribution of DL-Methionine to GHG reduction in broiler production was evaluated by carbon-Life Cycle Analysis (cLCA).

This case study focuses on life cycle GHG emissions and follows the requirement of the document “Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies (guidelines),” developed by ICCA and the Chemical Sector Group of the WBCSD.

2. Solutions to compare

2.1. Description of the solutions to compare

In this study, two options of broiler feed with different protein contents are compared: a study feed supplemented with DL-Methionine and a control feed without DL-Methionine as shown in Table 1. The study feed contains DL-Methionine to optimize its essential amino acid profile and thereby cut down on the excess amounts of other amino acids that cannot be utilized in broiler production. As a result, it is possible to reduce nitrogen excretion and N_2O emission during manure processing.

The control feed is not supplemented with DL-Methionine and has a higher overall protein content with excessive amounts of amino acids that are not utilized by the animal, resulting in proportionally higher nitrogen excretion.

On the other hand, as both feed options are assumed to satisfy all the nutritional requirements of broiler including methionine, they can provide the same function on the productivity of broiler meat as the final product.

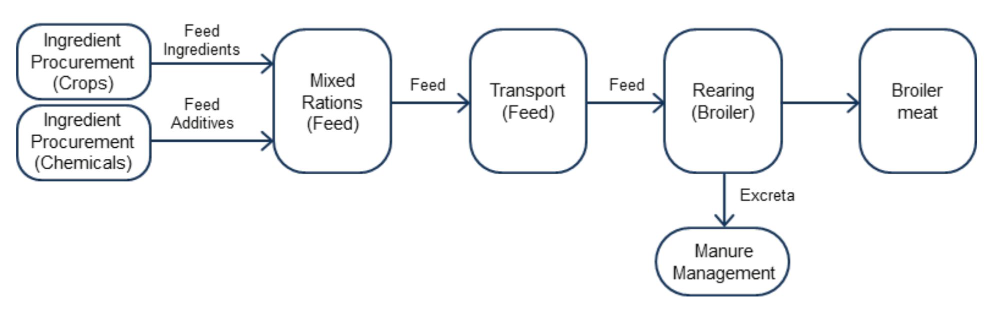
TABLE 1 - OPTIONS OF BROILER FEED

Option 1 (Study feed)	Option 2 (Control feed)
Broiler feed with DL- Methionine supplementation	Broiler feed without DL-Methionine supplementation

2.2. Level in the Value Chain

DL-Methionine is used as a feed additive to manufacture feed for livestock production. It is added and mixed with other feed ingredients such as corn, soybean meal and several micro nutrients to satisfy the nutritional requirement of animals. In this study, as two options of broiler feed with or without DL-Methionine are evaluated, the level in the value chain of this study can be defined as “the end-use level” in accordance with the guidelines. The value chain structure involved in the study is shown in Figure 1.

FIGURE 1 - VALUE CHAIN STRUCTURE



2.3. Definition of the boundaries of the market and the application

The several conditions for calculating GHG emissions in this study were based on the situation in 2011. The study forecast of 2020 was assumed under the same conditions as those in 2011 except for the annual broiler meat production.

The market share of the study feed containing DL-Methionine was estimated to be almost 100% in Japan in both 2011 and 2020.

3. Functional unit and reference flow

3.1. Functional unit

This study compared two options of broiler feed with different protein contents. It was assumed, however, that both products had similar amino acid scores and that the function of the final product, i.e, broiler meat, was comparable with both feed. This allowed us to focus on comparison between the two feed options.

The function defined for the study and the control feed was to produce broiler meat, and the functional unit was defined as 1 kg of broiler meat.

The intended audience who could benefit from supplementation of DL-Methionine is poultry farmers.
As livestock feed is consumed immediately, it does not have a service life.

Function:	Broiler production
Functional unit:	1 kg of broiler meat
Intended audience:	Poultry farmers

The function of feed is to rear broilers, that is, to provide appropriate nutrients required for maximizing broiler meat production.

A broiler feed must satisfy the requirements for metabolizable energy (ME) (3,210 kcal/kg) and digestible methionine plus cystine level (0.76%) to achieve adequate growth according to the nutritional requirement of a major broiler strain**[2]**. To satisfy these requirements, the broiler feed in this assessment had estimated crude protein (CP) contents of 19.5% with DL-Methionine and 25.6% without as shown in Table 2. The productivity of broiler meat was assumed to be equal between the two feed options because both feeds satisfy the nutrient requirements of the animal for maximum growth.

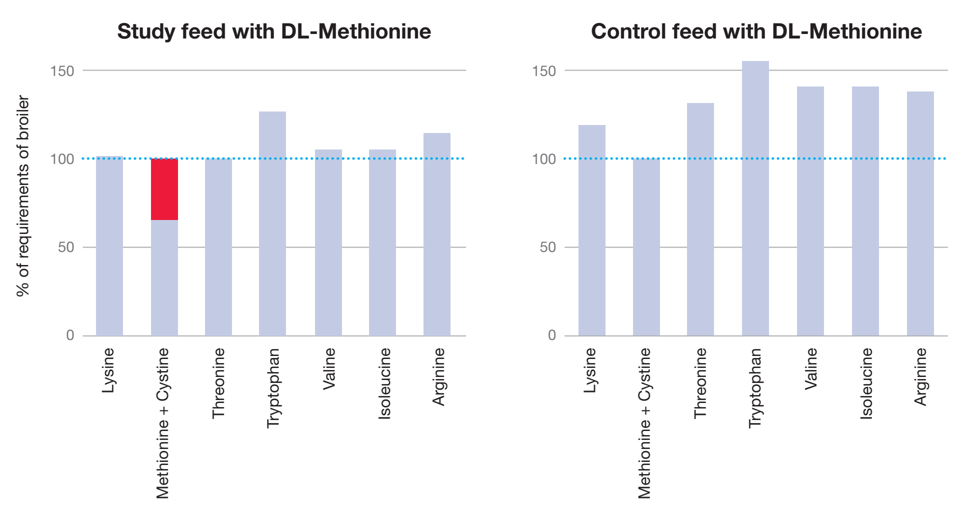
The essential amino acid profiles of the DL-Methionine-supplemented and unsupplemented feed are shown in Figure 2 as percentages of dietary requirements for broilers. Ideally, the feed should contain each of these essential amino acids at levels of 100% of the requirement for adequate production. Both of the broiler feed contain all essential amino acids at or more than 100% of what is required, which are considered equivalent in terms of feed functionality.

On the other hand, amino acids that are supplied in excess of 100% are not utilized by the animal and are excreted. By efficiently satisfying the requirements using DL-Methionine (indicated in red in Figure 2), less nitrogen is excreted after the broilers have eaten the study feed.

TABLE 2 - NUTRITIONAL VALUE OF THE BROILER FEED IN THE STUDY

Nutritional value	Study feed	Control feed
Metabolizable energy (ME)	3,210 kcal/kg	3,210 kcal/kg
Crude protein (CP)	19.50%	25.60%
Digestible methionine + cysteine	0.76%	0.76%

FIGURE 2 - ESSENTIAL AMINO ACID PROFILE EXPRESSED AS PERCENTAGES OF DIETARY REQUIREMENTS FOR BROILER



The feed used for calculation of GHG emissions were based on the feed formulation in 2011. The demand in 2020 was assumed to be the same as that in 2011.

The contribution to GHG emission reduction was calculated for all feed that are assumed to be manufactured in one year (2020) and used until the end of the life cycle.

Japan was selected as the location for the assessment.

3.2. Reference flow

The feed formulations are shown in Table 3. Both feed options were formulated and designed based on the nutritional requirements of a major broiler strain[2] and the nutritional composition of feed ingredients[3].

Except for the CP content, it was assumed that the same feeding practices were used in both feed options. This includes nutritional requirements for ME, digestible methionine plus cystine levels and other essential nutrients for broiler production.

It was assumed that each bird was reared for 48 days, which is the typical rearing period of a broiler in Japan, and reached 3.32 kg of body weight with 6.11 kg of feed per bird fed during this period according to the broiler strains manual[4]. The proportion of broiler meat against live body weight was assumed to be 63.7%[5].

TABLE 3 - FEED FORMULATION

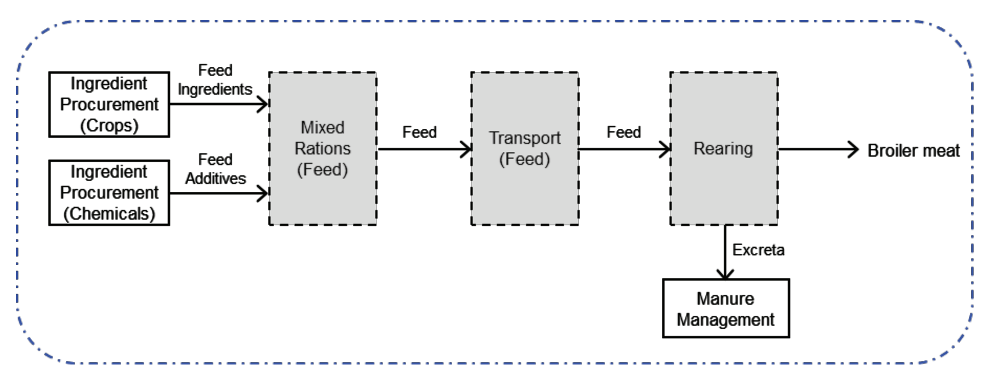
Ingredients	Study feed	Control feed
Corn	58.0%	45.0%
Soybean meal	33.3%	38.3%
Corn gluten meal	0.0%	7.8%
Soybean oil	5.5%	5.9%
Vitamins and minerals	3.0%	3.0%
DL-Methionine	0.2%	0.0%
Total	100.0%	100.0%

4. Boundary setting

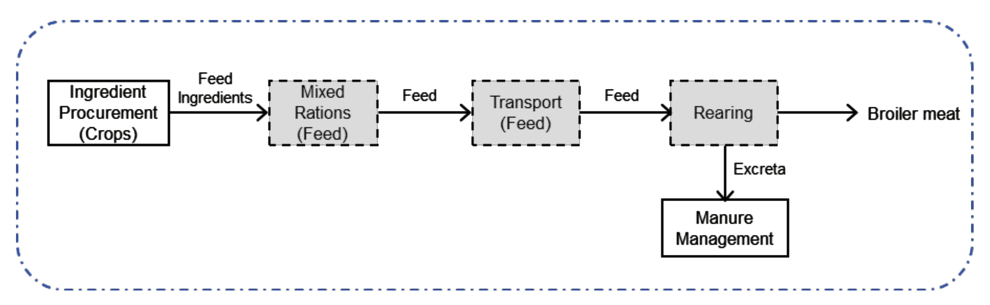
System boundaries defined for the two feed options are shown in Figure 3. This study mainly focused on the ingredient procurement and manure management processes to calculate GHG emissions.

As the other processes including mixed rations, transport and rearing of birds were the same under the two feed options, they were not taken into account to streamline the calculations as shown in Table 4.

SYSTEM BOUNDARY FOR THE STUDY FEED



SYSTEM BOUNDARY FOR THE CONTROL FEED



Note: Transport between the processes is not illustrated.

▭ Processes included in GHG emission calculation

Shared processes

- · - System boundary

TABLE 4 - SUPPLEMENTARY INFORMATION ON SYSTEM BOUNDARY

	Study product	Control product
Ingredient procurement	○	○
Production of feed	-	-
Distribution	-	-
Poultry rearing	-	-
Manure management	○	○

○: included in the calculation -: not included in the calculation

5. Calculation methodology and data

5.1. Methods and formulas used

This study starts with an analysis restricted to GHG as a first step and uses the simplified calculation method. In the study, trade-offs to other environmental impacts are not identified in the screening LCA. GHG emissions per unit of broiler meat were calculated in this study. Differences in GHG emissions associated with the two feed options, however, would occur at the levels of ingredient procurement and manure management. As the other processes were the same under the two feed options, they were not taken into account to streamline the calculations.

Simplified calculations were used as GHG emissions were expected to be equal during the processes that were the same under the two feed options and would not affect the absolute value of contributions to GHG emission reduction during the life cycles of these products.

Emissions unaccounted for

A. GHG emissions during the feed manufacturing process
B. GHG emissions during distribution (from feed mills to broiler farms)
C. GHG emissions during the rearing period at broiler farms

Typical percentages of unaccounted emissions to total emissions

Typical percentages of unaccounted emissions A, B and C to total emissions are not available.

In addition, the calculation of GHG emissions included only CO_2 in the ingredient procurement and N_2O in the manure management. In the ingredient procurement, CO_2 emission was approximately equal to GHG emissions at the level of feed manufacturing because the impact of other GHGs was likely to be minimal. In the manure management, GHGs except N_2O did not included in the calculation in accordance with the cLCA offset guideline because these emissions were likely to be similar for both feed options.

5.2. Allocation

No allocation was performed in this case study.

5.3. Data sources and data quality

The study uses secondary data from the CO_2 emission coefficient database for food-related ingredients and MiLCA software (Master Database Structure Ver. 1.2.0 and IDEA Ver. 1.1.0).

The two feed options were formulated in accordance with the nutritional requirements of the broiler strain[2]. The conditions of manure management process were based on a report in Japan[1].

6. Results

6.1. Avoided emissions

GHG emissions by ingredient

CO_2 emission on per kg of feed basis during feed manufacturing was calculated as shown in Table 5 according to the feed formulation shown in Table 3 using the CO_2 emission coefficient database for food-related ingredients and MiLCA software (Master Database Structure Ver. 1.2.0 and IDEA Ver. 1.1.0).

Although the applied CO_2 emission coefficient database is based on CO_2 data alone, we assumed that CO_2 emission was approximately equal to GHG emissions at the level of feed manufacturing because the impact of other GHGs was likely to be minimal.

The values on per kg of feed basis were converted into the functional unit (per kg of broiler meat) as shown in Table 6 based on the assumption of feed intake (6.11kg/bird), body weight at 48 days of age (3.32kg) and the proportion of meat against live body weight (63.7%).

TABLE 5 - GHG EMISSIONS DURING THE MANUFACTURE OF FEED INGREDIENTS (UNIT: KG CO_2e/KG OF FEED)

Ingredients	Study feed	Control feed
Corn	0.044	0.034
Soybean meal	0.058	0.067
Corn gluten meal	0	0.009
Soybean oil	0.025	0.027
Vitamins and minerals	0.071	0.071
DL-Methionine	0.019	0
Total	0.217	0.209

TABLE 6 - GHG EMISSIONS DURING THE MANUFACTURE OF FEED INGREDIENTS (UNIT: KG CO_2e/KG OF BROILER MEAT)

Ingredients	Study feed	Control feed
Corn	0.126	0.098
Soybean meal	0.168	0.194
Corn gluten meal	0.000	0.027
Soybean oil	0.074	0.079
Vitamins and minerals	0.205	0.205
DL-Methionine	0.054	0
Total	0.628	0.603

GHG emissions from waste management

GHG emissions from manure management were calculated under the following conditions. CO_2 and methane emissions from organic materials in the manure were not included in the calculation in accordance with the cLCA offset guideline because these emissions were likely to be similar for both feed options.

The percentage reduction in manure nitrogen was calculated by the following equation[6]:
% Reduction in manure nitrogen = 0.64 + 7.25 × % Reduction in feed CP

Since reduction in feed CP was 6.1% with DL-Methionine (calculated from the feed formulation Table), the calculated manure nitrogen reduction was 44.9%.

Assuming 2.62 g/bird/day of manure nitrogen content with the control feed, reduction of 1.18 g/bird/day of nitrogen was expected with DL-Methionine [nitrogen excreted/bird/day = 2.62 g/bird/day × (1 – 0.449) = 1.44 g/bird/day]. For 48 days of rearing, the total amount of nitrogen excretion was estimated to be 69.12 g/bird with DL-Methionine (1.44 g/bird/day × 48 days) and 125.76 g/bird without DL-Methionine (2.62 g/bird/day × 48 days).

Methods of livestock manure management include sun drying, thermal drying, composting, piling, incineration and methane fermentation. The percentages of the methods used in Japan are shown in Figure 4, and N_2O emission coefficients by manure processing method are shown in Table 7. GHG emissions from broiler manure management were calculated based on the manure nitrogen contents as shown in Table 8 and GHG emissions per kg of broiler meat are shown in Table 9.

FIGURE 4 - PERCENTAGES OF MANURE MANAGEMENT METHODS USED IN JAPAN[1]

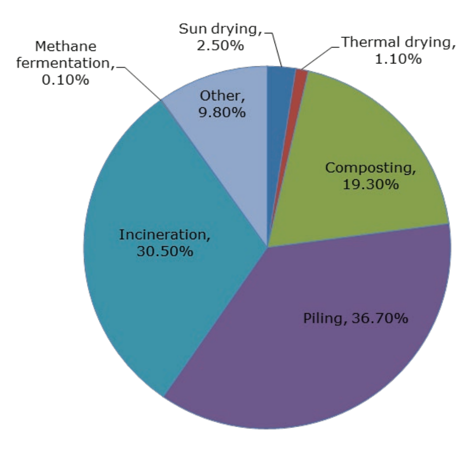
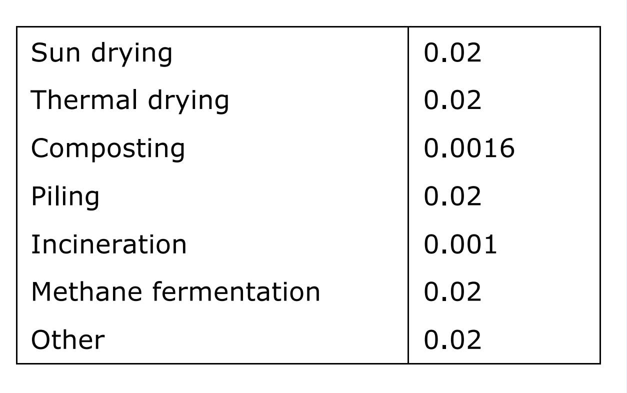
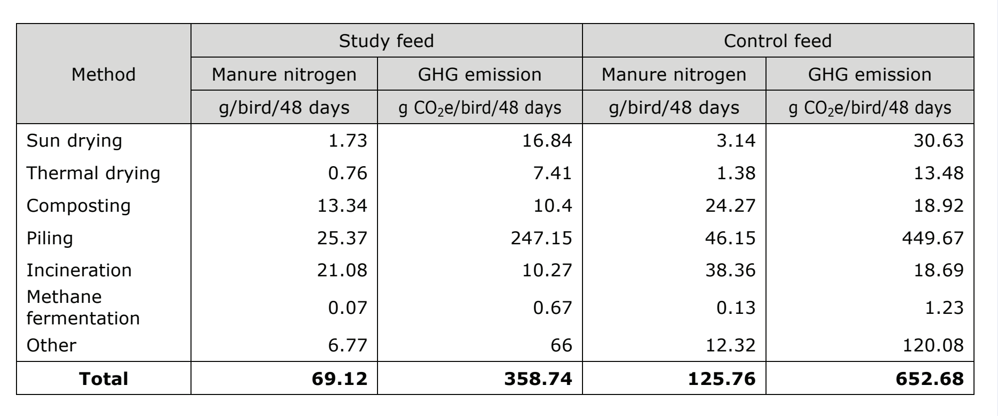


TABLE 7 - N2O EMISSION COEFFICIENTS BY MANURE PROCESSING METHOD[1] (UNIT: G N2O-N/G-N)



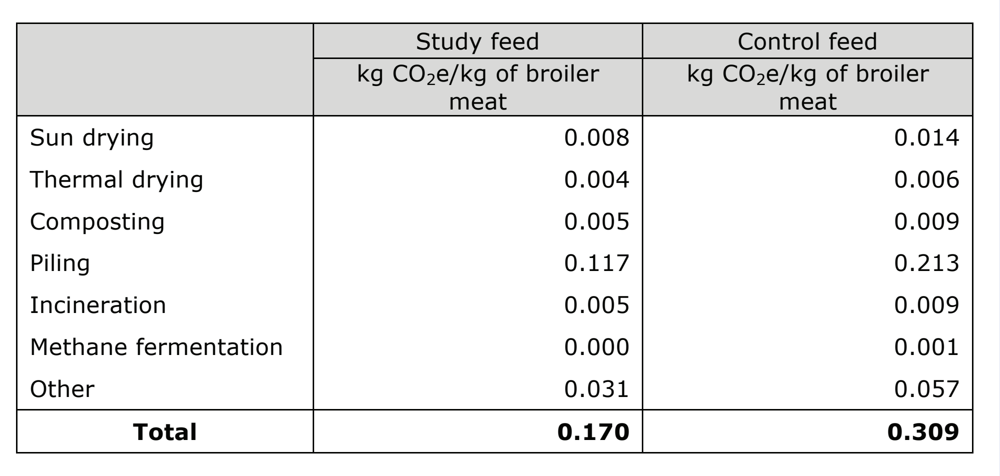
Sun drying	0.02
Thermal drying	0.02
Composting	0.0016
Piling	0.02
Incineration	0.001
Methane fermentation	0.02
Other	0.02

TABLE 8 - MANURE NITROGEN CONTENTS AND GHG EMISSIONS FROM MANURE



Method	Study feed		Control feed	
	Manure nitrogen	GHG emission	Manure nitrogen	GHG emission
	g/bird/48 days	g CO_2e/bird/48 days	g/bird/48 days	g CO_2e/bird/48 days
Sun drying	1.73	16.84	3.14	30.63
Thermal drying	0.76	7.41	1.38	13.48
Composting	13.34	10.4	24.27	18.92
Piling	25.37	247.15	46.15	449.67
Incineration	21.08	10.27	38.36	18.69
Methane fermentation	0.07	0.67	0.13	1.23
Other	6.77	66	12.32	120.08
Total	**69.12**	**358.74**	**125.76**	**652.68**

TABLE 9 - GHG EMISSIONS FROM MANURE MANAGEMENT (PER KG OF BROILER MEAT)



	Study feed	Control feed
	kg CO_2e/kg of broiler meat	kg CO_2e/kg of broiler meat
Sun drying	0.008	0.014
Thermal drying	0.004	0.006
Composting	0.005	0.009
Piling	0.117	0.213
Incineration	0.005	0.009
Methane fermentation	0.000	0.001
Other	0.031	0.057
Total	**0.170**	**0.309**

Life-cycle GHG emissions

Life-cycle GHG emissions for both of the study and control feed are shown in Table 10 and Figure 5.

It was estimated that the life-cycle GHG emissions were 0.798 kg CO_2e and 0.912 kg CO_2e per kg of broiler meat produced by the study and control feed, respectively.

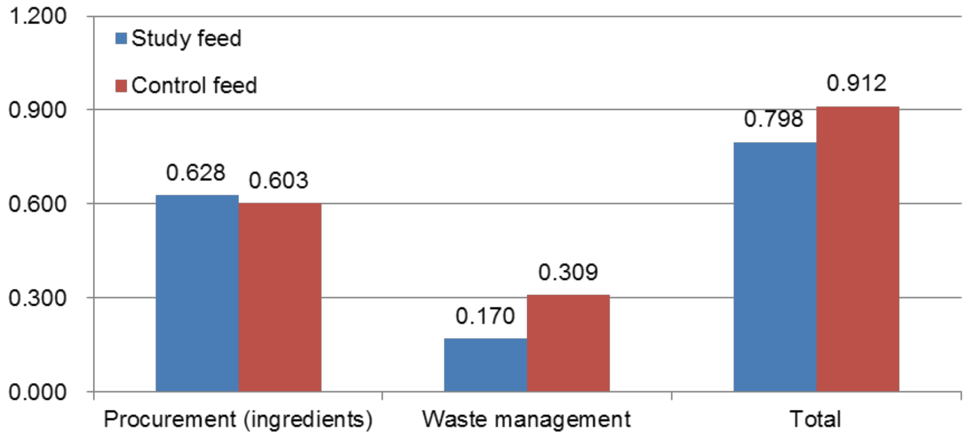
Contribution to GHG emission reduction per kg of broiler meat.

The estimated contribution of the study feed to GHG emission reduction was 0.114 kg CO_2e per kg of broiler meat, based on the difference in life-cycle GHG emissions between the two feed options.

TABLE 10 - GHG EMISSIONS AND CONTRIBUTION TO GHG EMISSION REDUCTION PER KG OF BROILER MEAT (KG CO_2e/KG OF BROILER MEAT)

	Study feed	Control feed
Ingredient procurement	0.628	0.603
Production of mixed feed rations	A	A
Distribution	B	B
Poultry rearing	C	C
Manure management	0.170	0.309
Life cycle total	**0.798**	**0.912**
Contribution	▲ 0.114	

FIGURE 5 - GHG EMISSIONS AND CONTRIBUTION TO GHG EMISSION REDUCTION PER KG OF BROILER MEAT (KG CO_2e/KG OF BROILER MEAT)



6.2. Scenario analysis

The contribution to GHG emission reduction in 2020 was estimated as follows and summarized in Table 11.

1. Poultry meat production in the study feed group: 1344.50 kt in 2011 and 1419.08 kt in 2020[7].
2. Contribution to GHG emission reduction per kg of broiler meat: 0.114kg CO_2e per kg of broiler meat
3. Overall contribution to GHG emission reduction: Contribution to GHG emission reduction per kg of broiler meat × amount of poultry meat production per year
   = 0.114 kg CO_2ekg-broiler meat × 1419.08kt poultry production
   = 161.77kt CO_2e

Based on the life-cycle GHG emission per kg of broiler meat with DL-Methionine (0.798 kg CO_2e), the total GHG emission was estimated to be 1,132.4k t CO_2e (0.798 kg CO_2e/kg broiler meat × 1419.08 kt = 1,132.426kt CO_2e) for the study feed in 2020.

TABLE 11 - CONTRIBUTION TO GHG EMISSION REDUCTION BY THE STUDY PRODUCT IN 2020

1) Inputs for 2020			
i)	Amount of poultry meat production	(kt)	1419.08
2) Contribution to GHG emission reduction in this input scenario			
-	Life-cycle contribution per kg of feed mix with DL-methionine	(kg CO_2e/kg broiler meat)	▲0.114
-	Contribution of the study product in 2020	(kt CO_2e)	▲161.77

7. Significance of contribution

DL-Methionine is the key component to contribute to the reduction of GHG emissions by cutting down on the excessive amounts of amino acids in broiler feed and thereby reducing the amount of nitrogen excreted. Therefore, the contribution of the chemical product to the solution is “extensive” in accordance with the guidelines. Contributions to the reduction of GHG emissions, however, can be attributed not only to the chemical industry but also to the entire value chain from feed ingredient levels to broiler producers.

8. Review of results

This report was prepared by translating and revising parts of the report “Innovations for Greenhouse Gas Reductions - Life Cycle Analysis of Chemical Products in Japan -” published by Japan Chemical Industry Association on Mar 2014 with reviewing by a technical committee in the association. The review focused on the methodology. While it did not include all the elements described in ISO 14044, the review did not take exception to the calculations of the GHG emissions.

9. Study limitations and future recommendations

As the production of feed, transport and rearing birds are shared processes between the study and control feed, they were not included in the GHG emission calculations in the present study. Although GHG emissions from these unaccounted processes should have been provided as percentages of total GHG emissions, reports or any other type of data were not available. In addition, the calculation of GHG emissions in the processes of ingredients procurement and manure management process only focused on CO_2 and N2O respectively due to the limitation of available data. These are one of the priorities for future work.

Finally, the focus of the present study is the assessment of broiler feed, and the future contribution to GHG emission reduction was estimated based on the projected demand for the year 2020. For layers, pigs, cattle and other livestock species, individual assessments are necessary to estimate GHG emissions in these sectors, because feed compositions are different among these animals.

10. Conclusions

This study calculates and proposes the reduction of GHG emissions during broiler production mainly focusing on ingredients procurement and manure management processes between two feed options based on secondary data and a simplified calculation methodology. The study revealed that decreasing nitrogen content in feed by supplementing chemically synthesized feed additive “DL-Methionine” can contribute to reduce GHG emissions from broiler production.

11. References

[1] National Greenhouse Gas Inventory Report of JAPAN (April 2013), National Institute for Environmental Studies, Japan

[2] ROSS Nutritional Supplement 2009, Aviagen

[3] Standard Tables of Feed Composition in Japan (2009), Japan Livestock Industry Association

[4] ROSS 308 BROILER: Performance Objectives 2012, Aviagen

[5] Handbook of poultry feed from waste - Processing and Use – Second Edition, Springer-Science+Business Media, B.V., 2000

[6] The Trend of Studies on Reducing Nutrient Excretion in Poultry and Pigs by Nutritional Approaches, Animal Science Journal 72 (8): J177-199, 2001

[7] OECD-FAO Agricultural Outlook 2012, OECD and FAO

12. Appendices

This report introduces effective methodology for reducing GHG emissions from livestock manure management by decreasing nitrogen content in feed with feed additive amino acids including DL-Methionine. The measure has been certified for swine and broiler production in the J-Credit Scheme, which is designed and operated to certify the amount of GHG emissions reduced and removed by approved methodologies within Japan.

Appendix: Reference materials

Report template for case study

TITLE of Case Study

Commissioner and performer of the study

1. Purpose of the study

2. Solutions to compare

2.1. Description of the solutions to compare

[Describe what solutions are being compared and provide relevant information about each solution.]

2.2. Level in the Value Chain

[Describe the level in the value chain at which the study is performed, including the reason why this level has been chosen. If the case study is conducted at the end-use level the usage of chemical product as part of the end-use application shall be included.]

2.3. Definition of the boundaries of the market and the application

3. Functional unit and reference flow

3.1. Functional unit

[Including:

- Description of function of the solutions to compare
- Functional unit
- Quality requirements: Indicate any quality criteria that are taken into consideration to ensure compared products are exchangeable for the typical customer in the selected market.
- Service life: Indicate service life of product taken into consideration and explain how the service life is determined.
- Time and geographical reference.]

3.2. Reference flow

[i.e. the amount of the chemical product on which the result of the study is based.]

4. Boundary setting

[Describe the boundaries of the case study:

- Describe the value chain steps of all solutions to compare, making explicit which processes are included and excluded from the case study.
- Include a flow diagram for each of the solutions to compare, indicating which parts are identical in the calculation of life cycle greenhouse gas emissions of the alternative solutions.
- Describe the cut off threshold and how the threshold was determined.]

5. Calculation methodology and data

[Report any relevant general information related to the calculation methodology, including the following sections. Each section should explicitly describe assumptions made with justification.]

5.1. Methods and formulas used

Note: In case the simplified calculation method has been used this should be mentioned explicitly in the report (at the beginning and in section 6), and the report requirements at page 24 of the guidelines should be taken into account.
http://www.icca-chem.org/ICCADocs/E%20CC%20LG%20guidance_FINAL_07-10-2013.pdf

5.2. Allocation

5.3. Data sources and data quality

[Specify which databases are used and report the data quality, including most important data in a Table.]

6. Results

6.1. Avoided emissions

[Avoided emissions shall be presented as the difference between the two emission profiles, and differentiated by life cycle phase.

- Clearly state that the credit for the avoided emissions belongs to the complete value chain.
- Report the full cradle-to-grave emissions of the reporting company's solution and the full cradle-to-grave emissions of the solution(s) to compare.
- Present the results in a Table (see Figure 1 and Table 1) .]

FIGURE 1 - GRAPH SHOWING THE RESULTS OF THE CASE STUDY

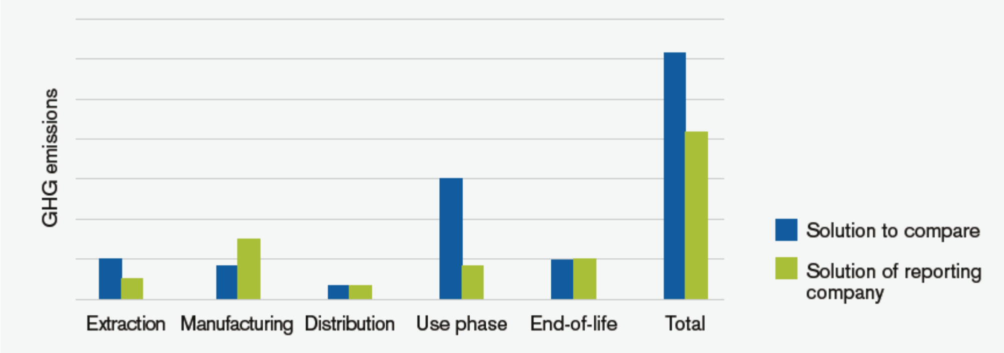


TABLE 1 - REPRESENTING THE RESULTS OF THE CASE STUDY

Emissions per life cycle phase (CO_2e)	Reporting company's solution	Solution to compare to
Raw material extraction		
Manufacturing/ processing		
Distribution		
Use phase		
End of Life		
Total emissions	**P1**	**P2**
Avoided emissions	**= P1 – P2**	

6.2. Scenario analysis

[Describe used scenarios, e.g. to take into account future changes, describe the results from scenario analysis]

7. Significance of contribution

[Describe the significance of the contribution of the studied chemical product to overall value chain avoided emissions (see Table 2 in Section 4.1 of the guidelines).
Describe the specific role of the product so that the reader understands how it is related to the greenhouse gas emission avoiding function of the end-use solution.
Describe attribution methods, if they are used in the study.]

8. Review of results

[Describe any review of the results (i.e., critical peer review) that were undertaken and which standard was followed]

9. Study limitations and future recommendations

[Describe any limitations of the study or improvements/ recommendations for future revisions of the study]

10. Conclusions

[Describe the main conclusions obtained from the study.]

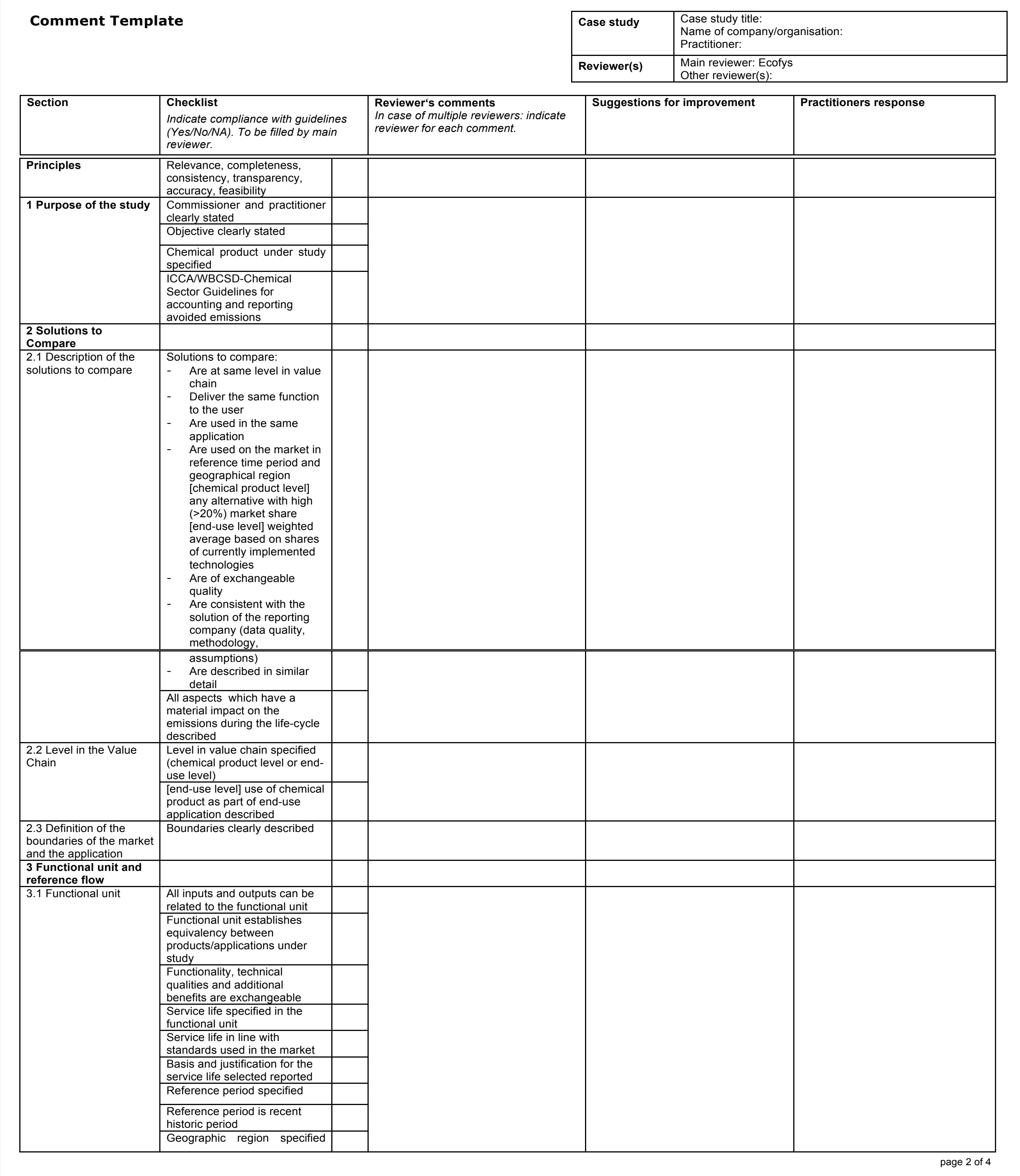
11. References

[List any relevant references (i.e. including a critique, especially if the conclusions of other studies are not consistent with the present case).]

12. Appendices

[Optional:
- Additional information on sources used
- Use of data from reporting company and databases
- Results from the critical review
- A glossary]

Comment template

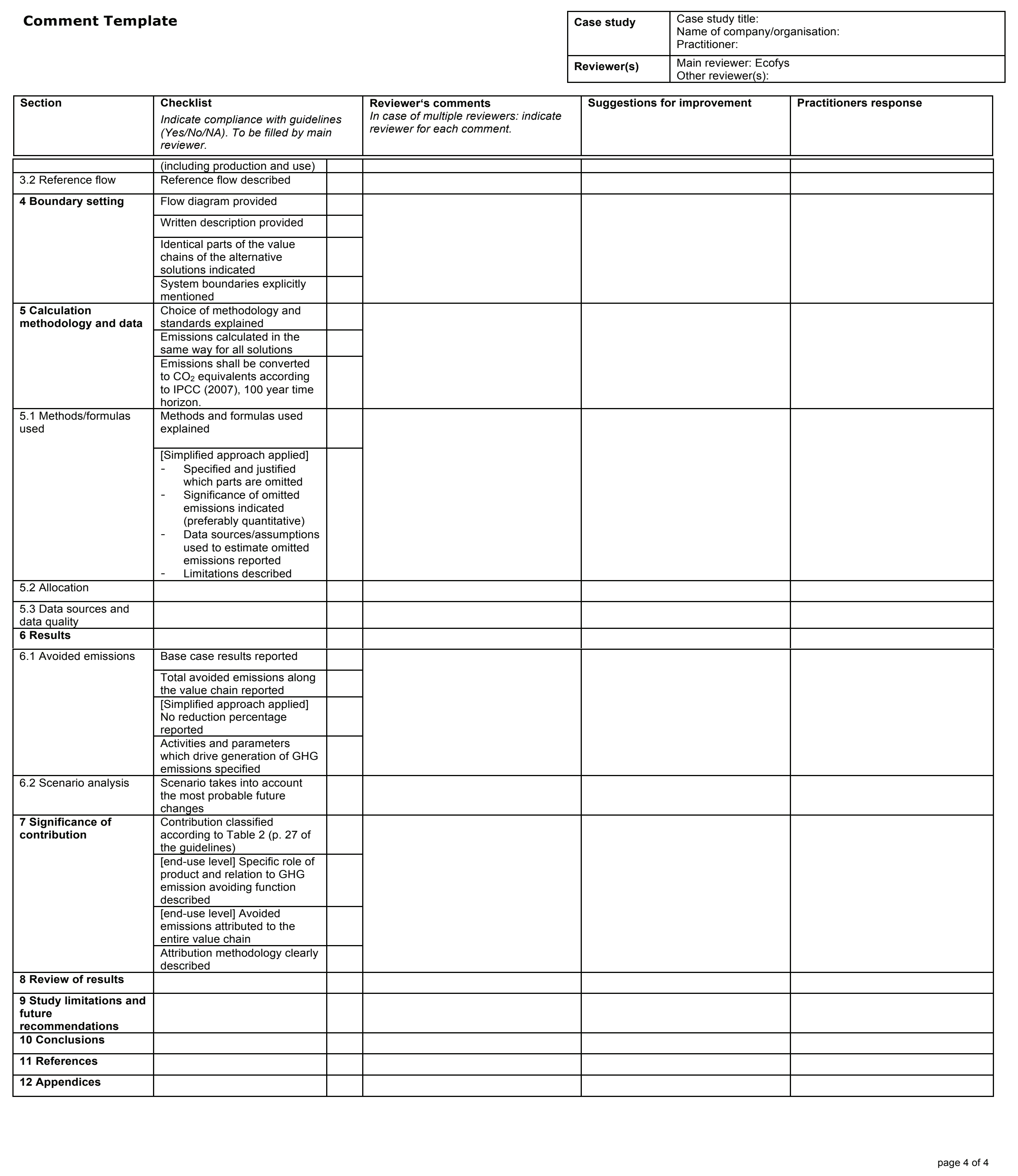


Comment Template

Case study	Case study title: Name of company/organisation: Practitioner:
Reviewer(s)	Main reviewer: Ecofys Other reviewer(s):

Section	**Checklist** *Indicate compliance with guidelines (Yes/No/NA). To be filled by main reviewer.*		**Reviewer's comments** *In case of multiple reviewers: indicate reviewer for each comment.*	**Suggestions for improvement**	**Practitioners response**
Principles	Relevance, completeness, consistency, transparency, accuracy, feasibility				
1 Purpose of the study	Commissioner and practitioner clearly stated				
	Objective clearly stated				
	Chemical product under study specified				
	ICCA/WBCSD-Chemical Sector Guidelines for accounting and reporting avoided emissions				
2 Solutions to Compare					
2.1 Description of the solutions to compare	Solutions to compare: - Are at same level in value chain - Deliver the same function to the user - Are used in the same application - Are used on the market in reference time period and geographical region [chemical product level] any alternative with high (>20%) market share [end-use level] weighted average based on shares of currently implemented technologies - Are of exchangeable quality - Are consistent with the solution of the reporting company (data quality, methodology, assumptions) - Are described in similar detail				
	All aspects which have a material impact on the emissions during the life-cycle described				
2.2 Level in the Value Chain	Level in value chain specified (chemical product level or end-use level)				
	[end-use level] use of chemical product as part of end-use application described				
2.3 Definition of the boundaries of the market and the application	Boundaries clearly described				
3 Functional unit and reference flow					
3.1 Functional unit	All inputs and outputs can be related to the functional unit				
	Functional unit establishes equivalency between products/applications under study				
	Functionality, technical qualities and additional benefits are exchangeable				
	Service life specified in the functional unit				
	Service life in line with standards used in the market				
	Basis and justification for the service life selected reported				
	Reference period specified				
	Reference period is recent historic period				
	Geographic region specified				

page 2 of 4



Comment Template

Case study	Case study title: Name of company/organisation: Practitioner:
Reviewer(s)	Main reviewer: Ecofys Other reviewer(s):

Section	**Checklist** *Indicate compliance with guidelines (Yes/No/NA). To be filled by main reviewer.*		**Reviewer's comments** *In case of multiple reviewers: indicate reviewer for each comment.*	**Suggestions for improvement**	**Practitioners response**
	(including production and use)				
3.2 Reference flow	Reference flow described				
4 Boundary setting	Flow diagram provided				
	Written description provided				
	Identical parts of the value chains of the alternative solutions indicated				
	System boundaries explicitly mentioned				
5 Calculation methodology and data	Choice of methodology and standards explained				
	Emissions calculated in the same way for all solutions				
	Emissions shall be converted to CO_2 equivalents according to IPCC (2007), 100 year time horizon.				
5.1 Methods/formulas used	Methods and formulas used explained				
	[Simplified approach applied] - Specified and justified which parts are omitted - Significance of omitted emissions indicated (preferably quantitative) - Data sources/assumptions used to estimate omitted emissions reported - Limitations described				
5.2 Allocation					
5.3 Data sources and data quality					
6 Results					
6.1 Avoided emissions	Base case results reported				
	Total avoided emissions along the value chain reported				
	[Simplified approach applied] No reduction percentage reported				
	Activities and parameters which drive generation of GHG emissions specified				
6.2 Scenario analysis	Scenario takes into account the most probable future changes				
7 Significance of contribution	Contribution classified according to Table 2 (p. 27 of the guidelines)				
	[end-use level] Specific role of product and relation to GHG emission avoiding function described				
	[end-use level] Avoided emissions attributed to the entire value chain				
	Attribution methodology clearly described				
8 Review of results					
9 Study limitations and future recommendations					
10 Conclusions					
11 References					
12 Appendices					

Selection criteria

In addition to the more detailed case study review template (see Section 7.2), an overview of the compliance with the ICCA & WBCSD guidelines was made by using a matrix (see below). The 12 criteria comprise a subset of the mandatory requirements in the guidelines. Each case study was reviewed to determine whether it complies with each of the 12 criteria.

	Category	Requirements ("shall" requirements)
1	Assessment of trade-offs	The reporting company shall check if trade-offs exist by doing a screening LCA.
		If trade-offs with other environmental impacts occur, the reporting company shall report on these environmental impact categories in the same way as it reports on GHG emissions and should consider not reporting avoided emissions at all.
2	Objective	The name and description of the organization(s) commissioning the study and that performing it ("the practitioner") shall be clearly stated.
		The objectives of the study shall be clearly stated.
		The reporting company shall specify what chemical product the study focuses on.
3	Selection of level in de value chain	The reporting company shall specify what level in the value chain has been selected for the definition of the functional unit of the study, including the reason why this level has been chosen.
		If the study is conducted at the end-use level, the description shall detail how the chemical product is used as part of the end-use application
4	Selection of solutions to compare	Solutions to compare shall be at the same level in the value chain
		Solutions to compare shall deliver the same function to the user
		Solutions to compare shall be used in the same application
		Solutions to compare shall be distributed/used on the market, and not in the process of being banned, in the reference time period and geographic region. (If the study is conducted at the chemical product level any alternative established product(s) with a high (combined) market share, based on sales volume in the reference year, shall be used. A sufficiently high market share is normally considered to be 20% and above. If the study is conducted at the end-use level, the weighted average based on shares of all currently implemented technologies for the same user benefit (including the studied end-use solution to which the chemical product contributes) shall be used.
		Solutions to compare shall be exchangeable for the typical customer in the selected market in terms of quality criteria
		Solutions to compare shall be as consistent as possible with the solution of the reporting company in terms of data quality, methodology, assumptions etc.
		Both the solution of the reporting company and the solution it is compared to shall be described in similar levels of detail
5	Boundary setting	The reporting company shall clearly describe how the boundaries of the market and the application have been defined
		A flow diagram shall be provided to show the value chains for each of the solutions being compared.
		A written description of the value chain shall be provided for clarification.
		The diagram shall indicate which parts of the value chain were assumed to be identical in the calculation of life cycle GHG emissions of the alternative solutions.
		All system boundaries shall be explicitly mentioned in order to clarify what processes are excluded or included.

	Category	Requirements ("shall" requirements)
6	Functional unit and reference flow	As in ISO 14040/44, a functional unit shall be defined to which all inputs and outputs of the product system can be related and which establishes equivalency between the products/applications under study.
		The functional unit shall be consistent with the goal and scope of the study.
		The reporting company shall specify the service life of the product or service in the functional unit
		The defined service life shall be in line with standards used in the market
		The reporting company shall clearly report the basis and justification for using the selected service life of the product or service
		The description shall include the reference flow, i.e. the amount of the chemical product on which the result of the study is based
		Companies shall specify the reference period chosen for the study.
		The reference period shall be a recent historic period.
		Companies shall specify the geographic region chosen for the study. This includes the geographic region where the product is produced as well as where it is used.
7	Use of scenarios	If a company wants to study avoided emissions in a future year, it shall first calculate and report avoided emissions in a recent historic period.
		The reporting company shall explain the scenarios used to project the future
8	Methodology applied	The reporting company shall describe the method used to account for emissions at each step.
		For both solutions the life cycle GHG emissions shall be calculated in the same way according to existing standards.
		The reporting company shall explain its choices of methodology and standards used
		The reporting company shall explain methods/formulas used to calculate the cradle-to-grave inventories
		When a simplified calculation is used the report shall say what parts are omitted and why
		When a simplified calculation is used the report shall indicate the significance of the emissions being omitted relative to total emissions of the reference case preferably in a quantitative manner but at least in a qualitative manner.
		The reporting company shall specify which activities and parameters drive generation of GHG emissions.
		When a simplified calculation is used data sources or assumptions used to estimate omitted emissions shall be reported.
9	Reporting & transparency	Companies shall report the main results of the study of its own solution and of the comparative solution (the "solution to compare to").
		The avoided emissions shall be presented as the difference between the two emission profiles, and differentiated by life cycle phase.
		When a simplified calculation is used reduction percentage, i.e. x% GHG emissions avoided in comparison to the reference solution, shall not be reported.
		Companies shall report the results of the base case and should report the scenario taking into account the most probable future changes.
		The reporting company shall describe the specific role of its product in such a way that the reader understands how it is related to the GHG emission avoiding function of the end-use solution.
		If the reporting company chooses to report the emissions associated with its activities (such as Scope 1 and Scope 2), then the reporting company shall clearly state that the reporting boundaries for activity emissions are different from those of avoided emissions.
		The description shall discuss all aspects of all compared solutions which have a material impact on the emissions generated during the life cycle
		Misplaced information
		Unclear information
		Missing/insufficient information

	Category	Requirements ("shall" requirements)
10	Attribution of avoided emissions	Avoided emissions calculated at the end-use level shall always be attributed to the complete value chain.
		The reporting company shall report total emissions avoided along the complete value chain and shall report the significance of the contribution of its product to the end-use solution according to the functionality approach as presented in Table 2.
		Companies shall clearly state that the credit for the avoided emissions belongs to the complete value chain.
11	Conclusions and limitations	The reporting company shall finalize the report with an overview of conclusions and implications from the study
		The reporting company shall finalize the report with an overview of additional steps/updates that might be planned to improve the results of its study
		When a simplified calculation is used the report shall clearly and noticeably describe the limitations of the study arising from omitting identical processes.
12	Data sources and data quality	Quality of data sources addressed in the text
		Data sources clearly references
		Traceability of data sources

Acknowledgements

ICCA would like to thank the people that have been involved in the avoided GHG emissions case studies project.

ICCA Energy and Climate Change Leadership Group / cLCA Task Force (2nd phase) Co-chairs:
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Ecofys has reviewed the cLCA case studies that were published at the ICCA website in December 2015 to check if they are in compliance with the ICCA & WBCSD guidelines of 2013 “Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies”. ICCA would like to thank Annemarie Kerkhof and Karlien Wouters of Ecofys for their review of the case studies and advice on the quality of the case studies.

February 2016

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About ICCA

The International Council of Chemical Associations (ICCA) is the worldwide voice of the chemical industry, an industry with a 2012 turnover of more than €3,000 billion (including observers & Responsible Care members). More than 20 million people around the globe are employed directly or indirectly by the chemical industry. ICCA members account for more than 90 percent of global chemical sales. ICCA focuses on key issues for the chemical industry such as the promotion and coordination of Responsible Care® and other voluntary initiatives. Learn more about the ICCA at **www.icca-chem.org**.

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