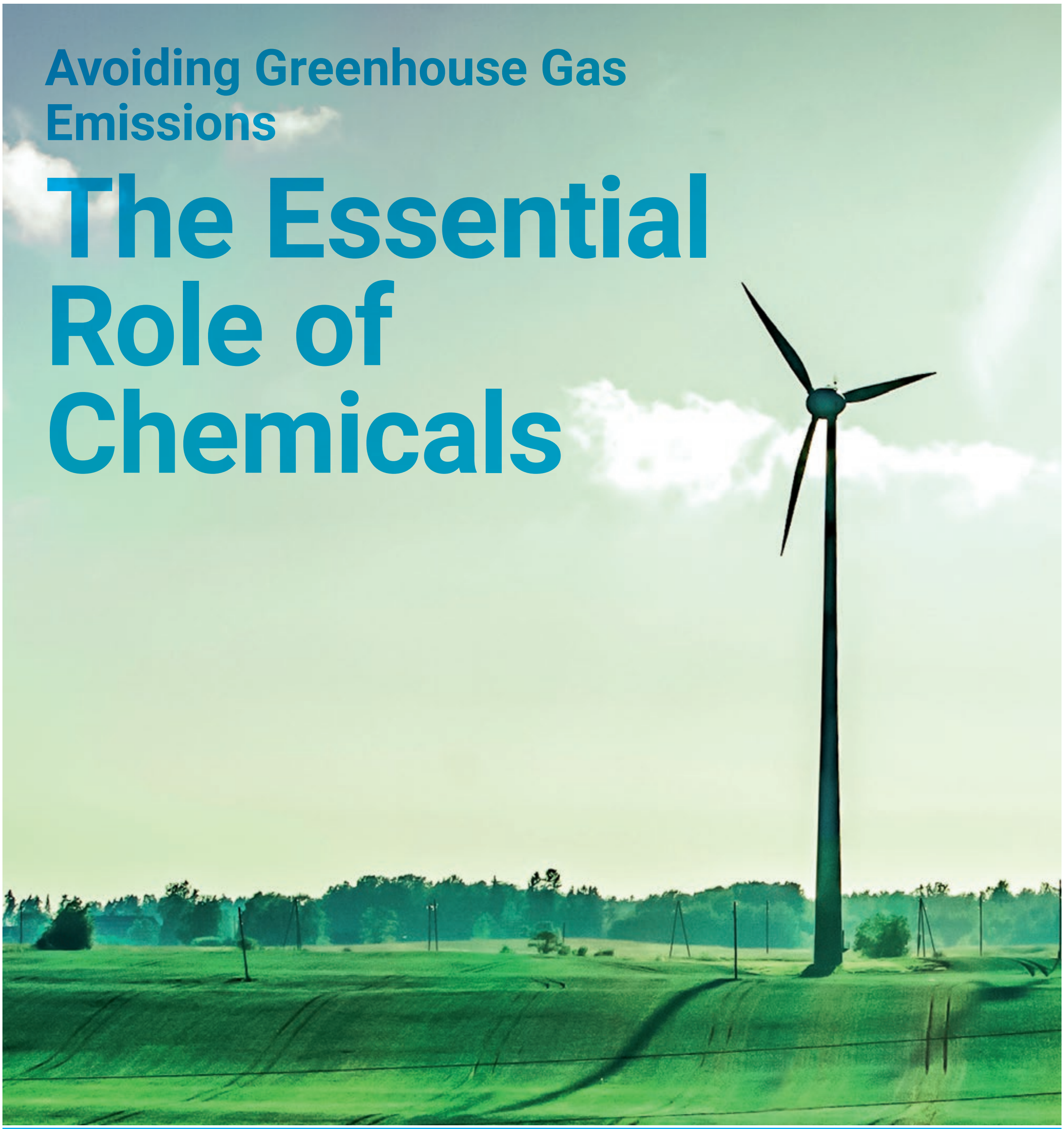
Avoiding Greenhouse Gas Emissions

The Essential Role of Chemicals



17 Case Studies

Technical reports

Applying the ICCA & WBCSD Avoided Emissions Guidelines

December 2017

INTERNATIONAL COUNCIL OF CHEMICAL ASSOCIATIONS

Foreword

The chemical industry has a key role to play on a game-changing path towards a low-carbon future. Reducing further its Greenhouse gas emissions during the manufacturing phase of chemical products is one part of this contribution. But the chemical sector can and will contribute via further supporting high efficiency processes and products in the many value chains where chemicals play a role.

Looking ahead in 6 key solution areas, ICCA estimates that by 2030, light materials for transportation, efficient buildings and lighting, electric cars, wind & solar power and improved tires together have the potential, at global scale, to avoid 2.5 Gigatons of greenhouse gas emissions globally every year. That's twice the amount currently emitted by all the cars in the world!

However a accounting for the reductions of these efficient processes and products can 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 emission reductions enabled by chemical components/ingredients in individual final solutions. The amount of the calculated 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 have together recognized the importance of establishing specific guidelines to help quantify and report the contribution of chemical products in reducing greenhouse gas emissions over the product life cycle. Guidelines were published in 2013 and revised in 2017.

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The goal of the present report is to illustrate and quantify, through examples offered by ICCA members and associations, to what extend efficient processes and solutions can contribute to greenhouse gas savings. It demonstrates how to quantify such "avoided emissions" in an unbiased way, applying the ICCA/WBCSD guidelines to individual cases. We hope this will encourage all chemical companies to apply the guidelines when calculating the avoided emissions enabled by their products. We expect this report will demonstrate that the evaluation of the avoided emissions must be carefully conducted, ensuring consistency and transparency.

We encourage all concerned parties, and especially chemical companies to develop robust studies. This will, I am sure, further enhance the credibility of industry as solution provider for a low carbon economy.

Bunro Shiozawa
Chair of ICCA Energy and
Climate Change Leadership Group

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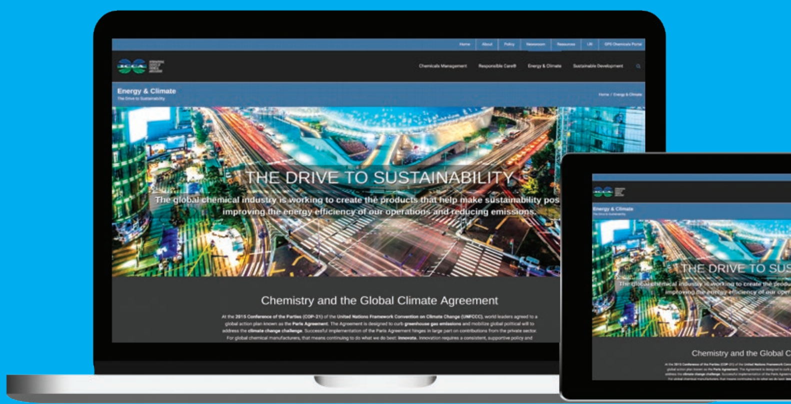
Related ICCA documents

Available on www.icca-chem.org/energy-climate

- Avoiding Greenhouse Gas Emissions - the Essential Role of Chemicals: 17 Case Studies - Summaries
- Accounting for and Reporting Greenhouse Gas Emissions Avoided along the Value Chain based on Comparative Studies: Guidelines:
- Greenhouse gas emission reductions enabled by products from the chemical industry: Quantifying the global potential



Executive summary

Purpose

The main purpose of this publication is to demonstrate, via robust and quantified examples that solutions enabled by chemical products can contribute to greenhouse gas savings. The case studies in this report were offered by ten companies and two associations. They 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”. Assembling these case studies is expected to motivate all stakeholders to feed climate change discussions with robust lifecycle assessment studies, and to motivate other chemical companies to generate high quality case studies. The present report on 17 case studies can also be used as an educational material to develop robust and more transparent LCA case studies.

Aim of the project

Through the publication of the technical reports of the avoided emissions life cycle assessment studies, and the accompanying summary fact sheets, the ICCA aims to achieve the following objectives:

1. Raise awareness about emission reduction potential of chemical products: Raise the awareness of stakeholders, including 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.
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 an increased number of publications on the ICCA website and elsewhere. The findings from those studies could feed a global picture of the overall potential of GHG emissions reductions by the chemical industry (and other sectors).
4. Promote full life cycle approach: With the case studies, the ICCA aims to promote the use of Life Cycle Assessment (LCA) and Life Cycle Thinking (LCT) as a comprehensive decision-support tool and concept for the chemical industry and its stakeholders.

Review of case studies presented

The studies were adapted from original work by companies by applying the ICCA/WBCSD Chemical Sector guidelines. To ensure that the case studies comply with these guidelines, ICCA commissioned Ecofys to review the first set of case studies (14 to 88) and Quantis to review the second, most recent series of case studies (89 to 159).

Ecofys and Quantis assessed the overall compliance with the guidelines. The summaries of the review findings for the case studies are presented on pages 7 to 12.

Case studies

The case studies in this report were offered by ten companies and two associations. The following companies and associations contributed: Akzo Nobel (contact: Klas Hallberg), BASF (Nicola Paczkowski), Braskem (Yuki Hamilton, Onda Kabe), Evonik (Christina Merz), Eastmann (Randy Waymire, Jason Pierce), India Glycols (Rakesh Bhartia), Japan Carbon Fiber Manufacturers Association (Hiroyuki Kamata), Japan Chemical Industry Association (Makoto Terauch), SABIC (Rajesh Mehta, Ananda Sekar), Solvay (Jean-François Viot, Pierre Coërs) and AGC Glass Europe (Guy Van Marcke), Sumitomo Chemical (Jiro Mori), Toray (Hiroyuki Kamata).

Other life cycle environmental impacts such as water and land use change were outside the scope of the studies and usually not considered in the assessments.

Case studies are presented in the form of technical reports giving details on the assumptions and calculations, and in the form of summary fact sheets available on **www.icca-chem.org/energy-climate**

Case studies summaries & review comments

1. BASF

External thermal insulation composite System for the refurbishment of a 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 to 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 by Ecofys

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.

2. Braskem

Rigid containers for chocolate drink powder in Brazil

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 by Ecofys

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.

3. Evonik

Feed additives - 4 amino acids for pig and broiler production: DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan

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 by Ecofys

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.

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 petro-chemical-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 from 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 by Ecofys

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.

5. The Japan Carbon Fiber Manufacturers Association (JCMA)

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

Brief description of case study

This case study compares two aircraft, one that consists of 50 wt.-% of carbon fibre reinforced plastic (CFRP) and one, conventional, that consists of 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_2e in a 10-year period.

Review comments by Ecofys

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.

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 also 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 by Ecofys

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, although this has a significant influence on the total avoided emissions.

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 1,000 square meter of packaging film compared to the conventional three layer PE packaging film.

Review comments by Ecofys

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.

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 5,600 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 by Ecofys

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 a good example of how light-weight car parts can and do reduce GHG emissions when driving a car.

9. SUMITOMO CHEMICAL

Broiler production with feed additive DL-Methionine

Brief description of 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 gas emissions during the 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 by Ecofys

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.

10. AkzoNobel

A comparative life cycle study of three fouling control systems for marine vessels

Brief description of case study

Intersleek 1100SR is a biocide-free fluoropolymer fouling control system which improves the coating's performance compared to the silicon based fouling control system, Intersleek 700, and the biocide fouling control system, Intersmooth 7460HS. Intersleek 1100SR ensures lower surface hull roughness, better coefficient of friction and better foul release properties, which, relatively to the Intersmooth 7460HS system, leads to reduced fuel consumption and avoided in-service emissions of up to 9%. The lifecycle study covers the vessel's full life-cycle. Fuel and lube oil consumption have been considered separately.

Review comments by Quantis

See below.

11. BASF

The Green Sense® Concrete solution – optimizing concrete mixtures by reducing cement content

Brief description of case study

Concrete is generally produced from a mixture of paste and aggregates. The paste is composed of cement and water and coats the surfaces of the fine and course aggregates. Cement, a fundamental component of concrete, generates a large carbon footprint during its production from the two processes of combustion and calcination. Chemical admixtures are added to modify or improve specific concrete properties. The cement production process results in high levels of greenhouse gas (GHG) emissions. The life cycle assessment study compares the environmental impacts of a conventional concrete mixture with an optimized Green Sense® Concrete mixture.

Review comments by Quantis

See below.

12. Braskem

Polypropylene (PP) containers for water-based paints

Brief description of case study

Brazil is one of the five largest markets for paints. In 2014, 1397 million liters of paint were produced, and this market is essentially dominated by tinplate (TP) pails. With the objective of proposing a solution to the paint pail market to reduce environmental impacts, Braskem developed an alternative packaging that is lighter and more resistant to corrosion, based on polypropylene (PP). Replacing tinplate rigid containers by Polypropylene containers for waterbased paints in Brazil can lead to a 18% reduction in GHG emissions amounting to 0.6 $kgCO_2e$ per container, over the whole lifecycle of the paint containers.

Review comments by Quantis

See below.

13. Eastman Chemical Company

Alternative product distribution logistics and greenhouse gas emission reduction

Brief description of case study

The study characterizes the avoided emissions associated with an innovative mode of chemical product distribution logistics between Eastman and other chemical company partners, called "Alternate Methods of Supply" (AMS). AMS can be used when two chemical companies produce a practically identical and mutually interchangeable chemical product in two separate geographic regions. This study was performed to better understand the life cycle impacts of the Eastman supply chain, and of distribution swaps between 2 chemical companies.

Review comments by Quantis

See below.

14. Evonik

Feed additives – 5 limiting amino acids for pig and broiler production: DL-Methionine, L-Lysine, L-Threonine, L-Tryptophan and L-Valine

Brief description of case study

In this case study, a supplemented feed mix incl. cristalline amino acids is compared to two non-supplemented feed mixes based on soybean as protein rich feed ingredient in one case and soybean and rapeseed in the second case. This is conducted for both animals, broiler and pigs. Supplementing animal feed with essential amino acids can save significant amounts of feed raw materials, resulting in minimized use of arable land for crop production and thus, fewer CO_2eq emissions. Furthermore, feed supplementation with these essential amino acids reduces both nitrogen and greenhouse gas emissions resulting from feeding and excretion.

Review comments by Quantis

See below.

15. Sabic

Renewable Polyethylene based on HVO (Hydrotreated Vegetable Oil) diesel

Brief description of case study

The Life Cycle Assessment study evaluated GHG emissions linked to polyethylene produced via two renewable routes: 1. Waste animal fats based renewable diesel and 2. Palm oil fatty acids based renewable diesel. These are compared with fossil naphtha route to produce polyethylene. Results indicate that the animal fats based route leads to a significantly lower carbon footprint than the fossil route. For the palm oil route, complete capture of methane emissions during palm oil processing is critical to ensure lower carbon footprint. Likewise, palm oil plantation must not have been associated with recent land transformation (forests to plantation) for it to have lower GHG emissions than the fossil route.

Review comments by Quantis

See below.

16. Solvay and AGC Glass Europe

Double-glazed windows in buildings and contribution of sodium carbonate in avoiding greenhouse gas emissions

Brief description of case study

GHG emissions can be avoided by replacing existing single glazing with double glazing windows in houses in Europe. Overall estimated avoided emissions resulting from such replacement amount to 3,400 kg CO_2 eq. per m^2 of glazing over a 30 year service lifetime.

The contribution of sodium carbonate is “extensive” according to the ICCA/WBCSD guidance, because it is an indispensable raw material to make glass. Extrapolation to the real European market gives a figure of 360 million tonnes of CO_2 emissions that will be avoided for every single year of replacement of windows in Europe. The contribution of sodium carbonate, a key raw material for glass, is essential to avoid these emissions. Its quantification relies on specific assumptions.

Review comments by Quantis

See below.

17. Toray

100% Bio-based Polyethylene Terephthalate (PET)

Brief description of case study

In shifting towards a low carbon and oil independent society, plastic products from non-petroleum based feedstocks are desired, while innovation in petroleum usage as energy sources has been progressing. Toray’s solution is the 100% bio based polyethylene terephthalate (PET) for materials of polyester fibers, which are one of the most well-used textiles in the world. The study compares the lifecyle GHG emissions of one kilogram of two alternative kinds of PET as the material to make polyester textile products. Toray’s solution is a 100% bio based PET, while the reference solution to compare to is the conventional petroleum based PET. The avoided emissions in the base case amount to 1.08 kgCO_2e/kg of PET. The possible impact of the land use change due to bio-based feedstocks has been estimated at 15.1 m^2 of cropland during a year to produce the bio based feedstocks for 1kg of PET.

Review comments by Quantis

See below.

Reviews comments by Ecofys (case studies 1-9) and Quantis (case studies 10-17)

For case studies 1-9, summaries of the reviews by Ecofys carried out in accompany every summary description (see above).

For case studies 10-17 reviewed in 2017, the review by Quantis showed the following :

- In terms of structure, case studies fully comply with the Guidance, and are generally clear about the basis for comparison (“solution to compare to”).

- They are also generally clear about the selected functional unit, the geographic scope and time frame, the basic calculation assumptions, and the data sources.
- Discussions in general are of course ongoing on data accuracy and on allocation for multi-product processes.
- The reviews highlighted some differences in the quality of the case studies and the approach to LCA by the different companies.

Statement by Quantis

"Eight case studies applying the updated version of the ICCA & WBCSD Avoided Emissions Guidance (version of 2013 updated in 2017) have been produced. These case studies have been prepared by AkzoNobel, BASF, Braskem, Eastman, Evonik, SABIC, Solvay, and Toray on the respective topics of fouling control systems, green concrete solutions, polypropylene vs tinplate containers for water-based paints, alternative product distribution logistics, feed additives, biobased vs conventional polypropylene, double-glazed vs single-glazed windows, and biobased vs conventional polypropylene terephthalate.

The case studies have been reviewed by Quantis. The review meant to assure that case studies follow the updated version of the ICCA/WBCSD Guidance in terms of structure as well as requirements. The review was also an opportunity to check whether the case studies used sound methods to calculate the avoided emissions, in terms of life cycle assessment calculation and of robustness of input data.

This review process allowed us to have all case studies aligned with the updated Guidance. Overall, the case studies provide examples showing where products from the chemical industry can contribute to reduce greenhouse gas emissions in their application. They were also a good opportunity to show the applicability of the updated Guidance.

In terms of structure, the case studies fully comply with the Guidance.

Case studies are generally clear about the basis for comparison ("solution to compare to"), the selected functional unit, the geographic scope and time frame, and the basic calculation assumptions, and the data sources.

Regarding detailed information on methodology and data, some case studies are more clear and extensive than others in terms of data transparency, for example in presenting key inputs data or formula so that reported avoided emissions results can be recalculated and challenged. To ensure robustness, the Guidance requires case studies to assess the possible influence of key assumptions on final results. This aspect is not systematically addressed. In particular, it should be noted that the influence of the occurrence or not of land use change in the production of feedstock used to produce bio-based chemicals is a topic that should be addressed more extensively in the two concerned case studies. Also, the potential trade-offs between the carbon footprint and other environmental impact categories is not clearly identified in all case studies."

Case study reports

Case 1 External thermal insulation composite system for the refurbishment of a 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.

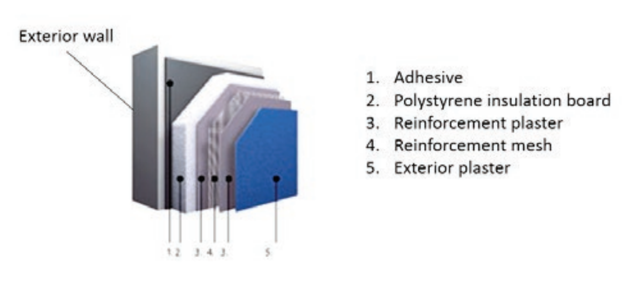
The study is a life cycle assessment including all material and energy inputs and outputs from raw materials acquisition through production, use and disposal (cradle-to-grave analysis). The study focuses on life cycle greenhouse gas emissions and follows the requirements of the Guidelines from the chemical 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

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

assumed. The U-value of 0.3 W/(m²*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/(m²*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/m^3) 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]

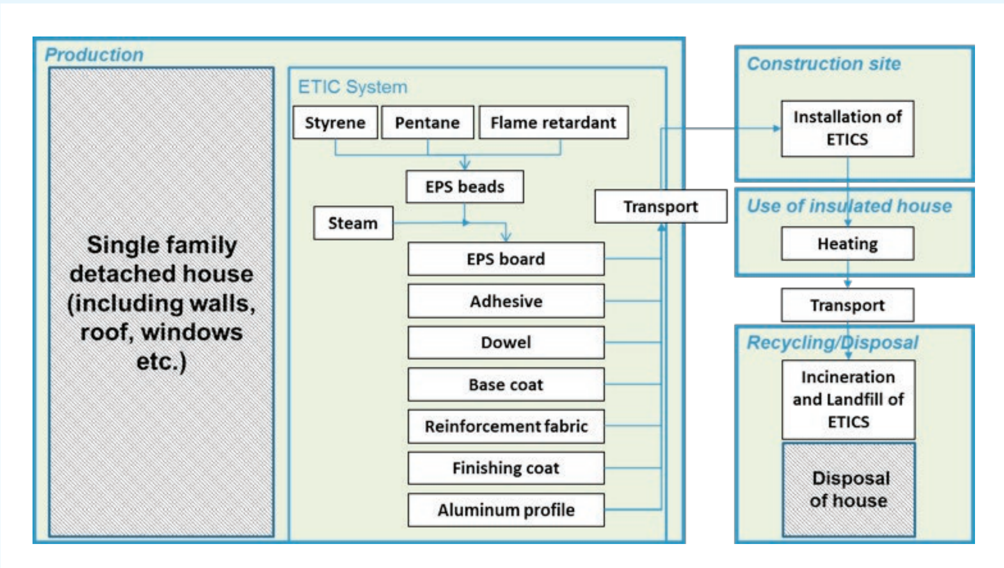
- Installation of the ETIC System: The ETIC System is assembled at the construction site.[9] All material and waste flows linked to the installation were included in the analysis. Only the energy requirements, such as the electricity for drilling the dowel holes were excluded since their contribution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

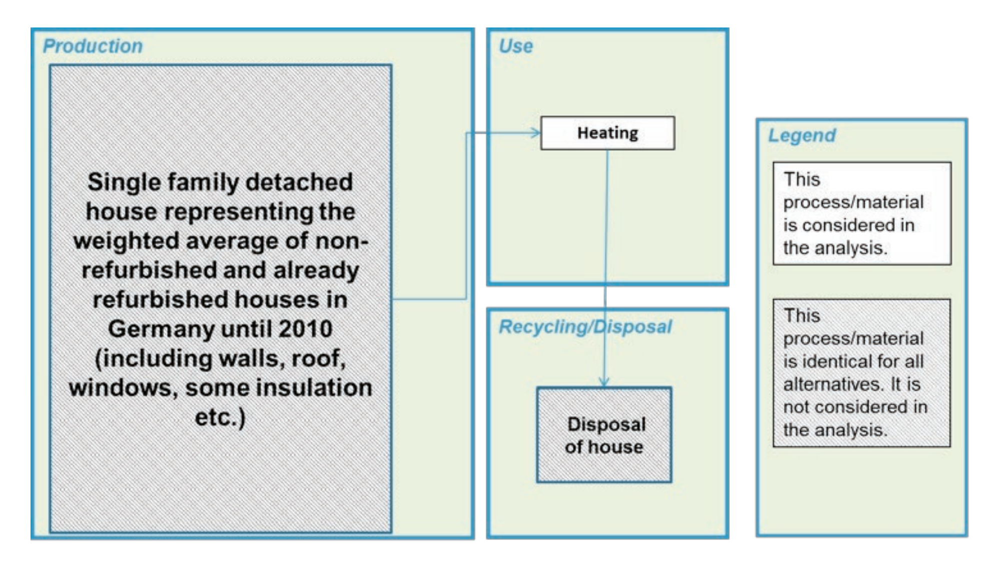
- Disposal: At the end of the defined service life, disposal of the ETIC System is necessary. 90% of the EPS is incinerated with energy recovery, while the remaining components are landfilled.[9]

- 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.

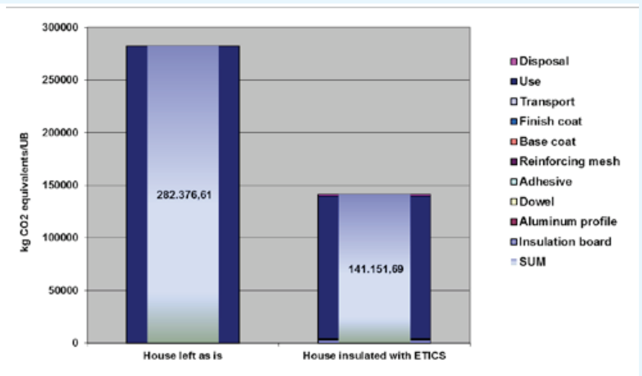
6. Results

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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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/(M²*K))[18]

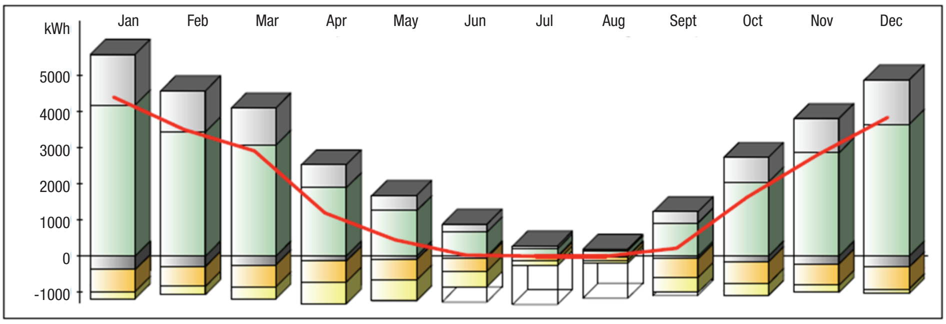
ENERGY LOSSES

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/(M²*K))[18]

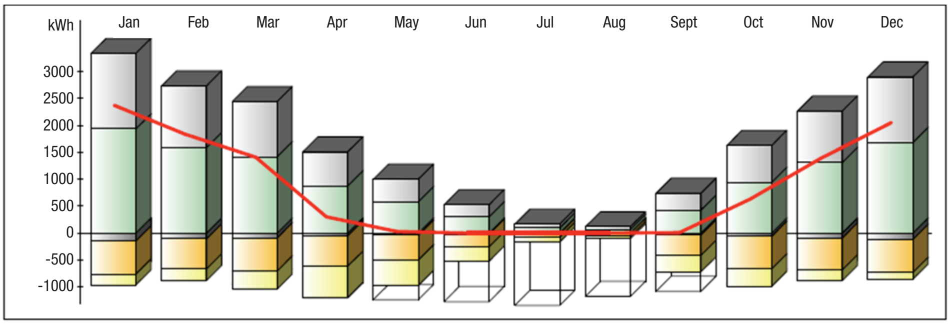
ENERGY LOSSES

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/(m²a)

Surface-related
annual heating needs = 61,38 kWh/(m²a)

Volume-related
annual heating needs = 19,64 kWh/(m²a)

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

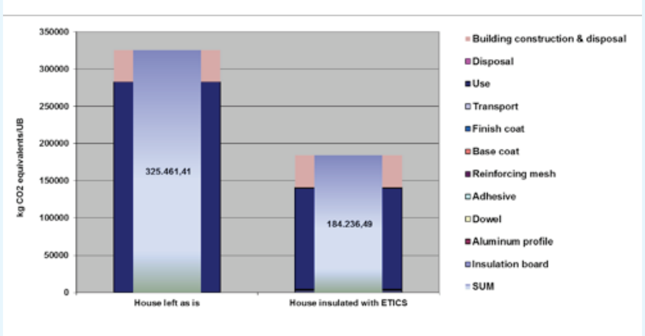
12.2. Evaluation of the impact of considering construction and disposal of the house on the results of the study

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 Rigid containers for chocolate drink powder in Brazil

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

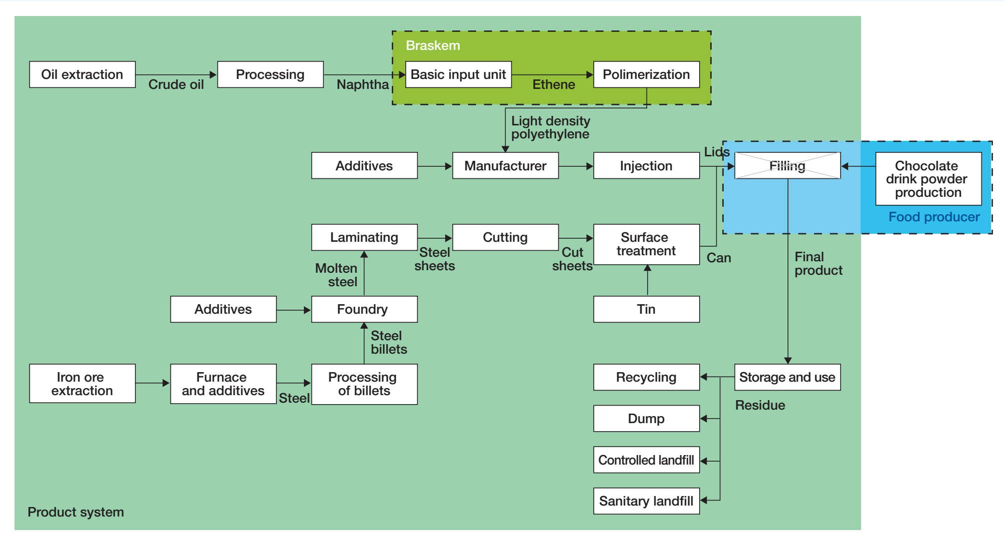
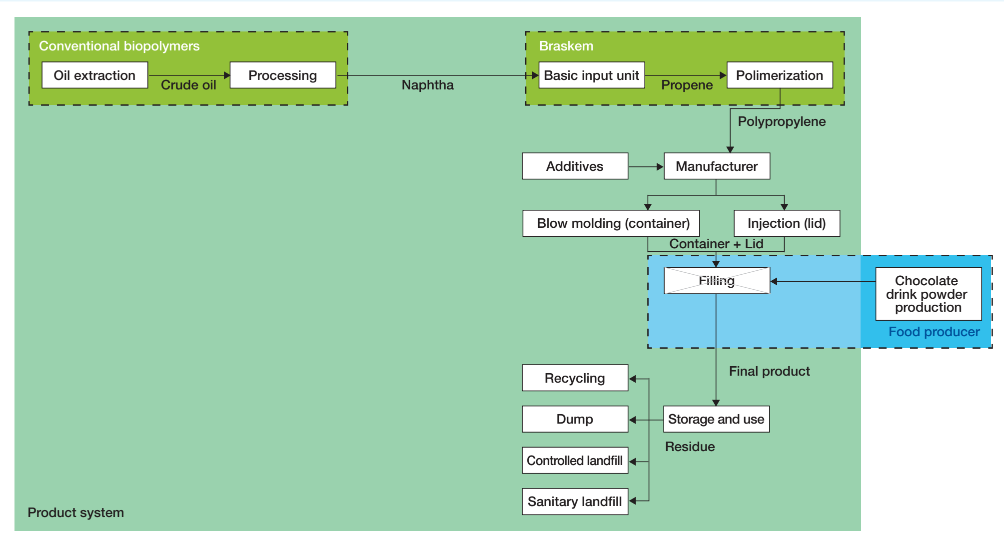


FIGURE 2 - PRODUCT SYSTEM FOR POLYPROPYLENE (PP) CONTAINERS



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
PP Container	Seal	Liquid packaging board, at plant/RER U*	Ecoinvent v2.2 based on [Habersatter et al 1998] and environmental reports of Scandinavian producers	1998-2001
PP Container	Seal	Polyethylene, HDPE, granulate, at plant/RER U*	Ecoinvent v2.2 based on [Boustead 2005]	2005
PP Container	Seal	Production of liquid packaging board containers, at plant/RER U*	Ecoinvent v2.2 based on [Habersatter et al 1998] and [Tetrapack 2001]	1998-2001
PP Container	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
PP Container	Label	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
Tin Plate Container	Body	Hot rolling, steel/BR U*	Ecoinvent v2.2 based on [IPCC 2001]	2001
Tin Plate Container	Body	Tin plating, pieces/BR U*	Ecoinvent v2.2 based on data from an established galvanizing company in central Europe	2001-2005
Tin Plate Container	Body	Sheet rolling, steel/RER U*	Ecoinvent v2.2 based on [IPCC 2001]	2001
Tin Plate Container	Body	Steel product manufacturing, average metal working/RER U*	Ecoinvent v2.2 based on eight environmental reports of companies in the engineering business	2002-2005
Tin Plate Container	Lid	Polyethylene, LDPE, granulate, at plant/RER U	Ecoinvent v2.2 based on [Boustead 2005]	2005
Tin Plate Container	Lid	Injection moulding/RER U*	Ecoinvent v2.2 based on [Habersatter et al 1998] and [Boustead 1997]	1997-1998
Tin Plate Container	Seal	Aluminium, primary, at plant/RER U*	Ecoinvent v2.2 based on [EAA 2000]	2000
Tin Plate Container	Seal	Sheet rolling, aluminium/RER U*	Ecoinvent based on [IPCC 2001]	2001
Tin Plate Container	Seal	Aluminium product manufacturing, average metal working/RER U*	Ecoinvent v2.2 based on eight environmental reports of companies in the engineering business	2002-2005
Tin Plate Container	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
Tin Plate Container	Label	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	

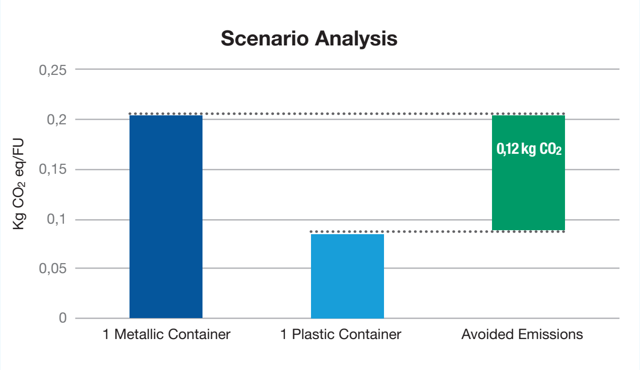
"Raw material" life cycle stage refers to manufacture of the PP resin and to the manufacturing of steel plates and zinc extraction. This stage, for the tinplate container, is dominated by the extraction of iron ore, the production of pig iron in blast furnace and the production of low alloyed steel from 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.

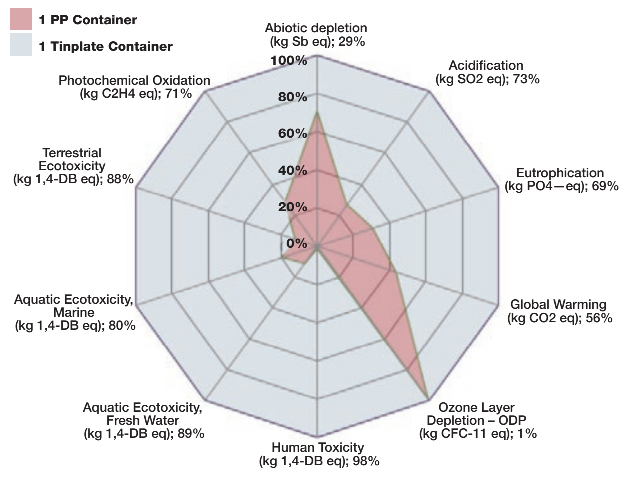
The GHG emissions and the Avoided figure can be seen on Figure 3.

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.

11. References

[1] ABEAÇO. Associação Brasileira de Embalagens de Aço, 2012. www.abeaco.org.br.

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Case 3 Feed additives – 4 amino acids for pig and broiler production: DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan

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 ones.

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 NO_x	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

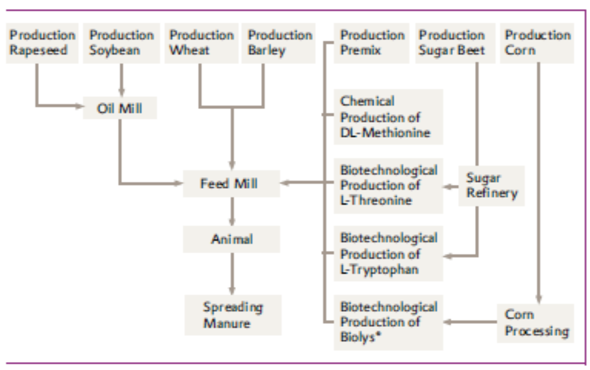
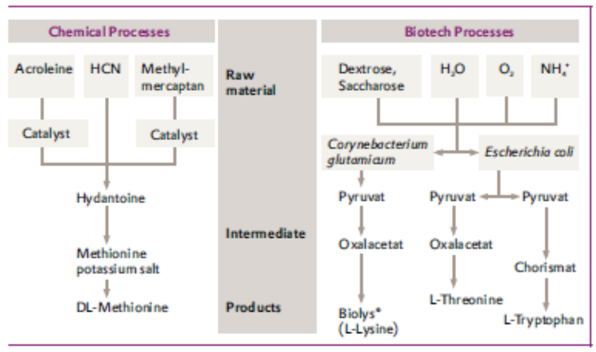


FIGURE 6 - RELEVANT MATERIAL FLOW AND RAW MATERIALS FOR THE RESPECTIVE TYPE OF MANUFACTURING



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.

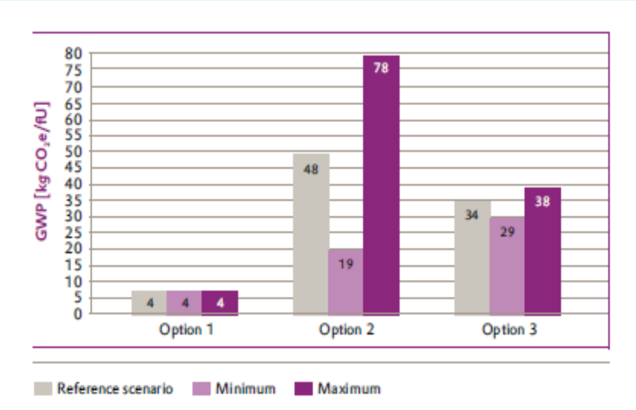
Broiler production - Sensitivity analysis of "land use change soya"

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.

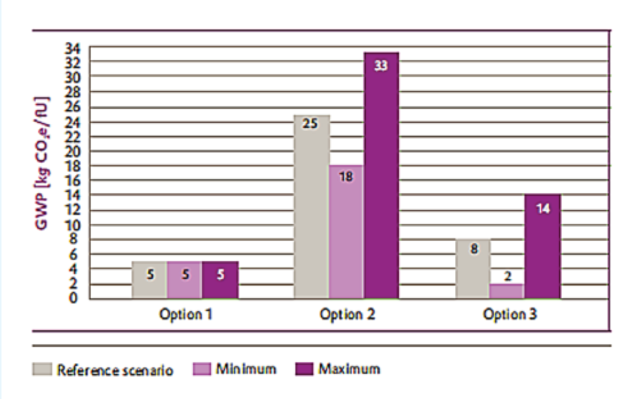
Swine production - Sensitivity analysis "land use change soya"

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

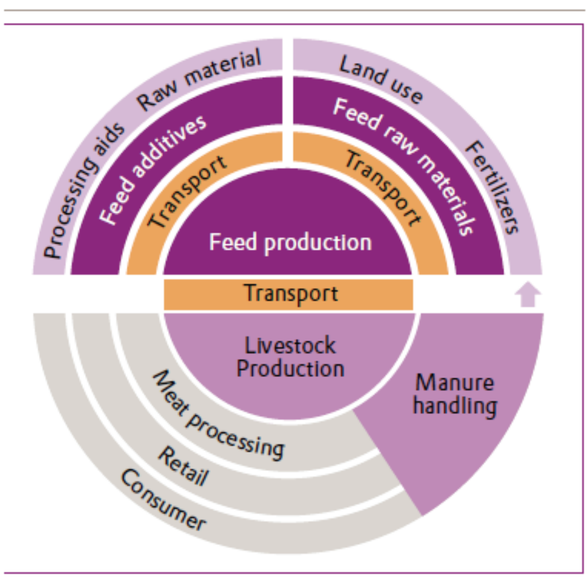
Process	Origin
DE: Soybean meal import mix (partly with LUC)	Individual data sets: PE Int., import mix: Evonik (taken from statistics)
DE: Soybean oil import mix (partly with LUC)	Individual data sets: PE Int., import mix: Evonik (taken from statistics)
CA: Rapeseed meal PE	Individual data sets: PE Int.
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

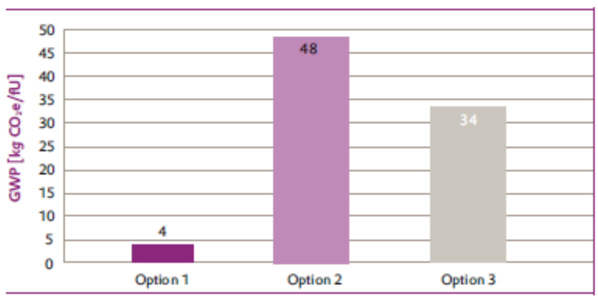


FIGURE 11 - GLOBAL WARMING POTENTIAL GWP100 [CML 2001] OF BROILER PRODUCTION BROKEN DOWN BY CONTRIBUTIONS OF INDIVIDUAL FACTORS

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

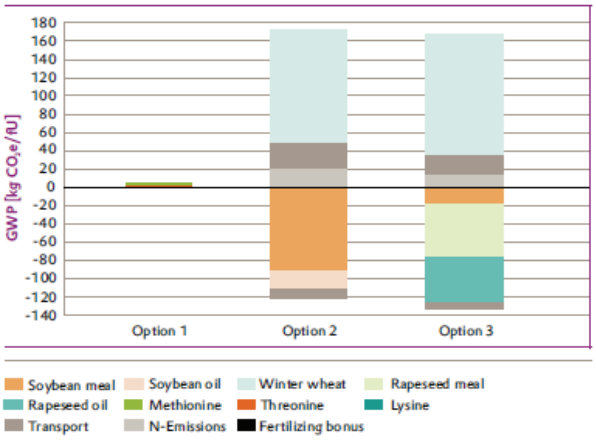
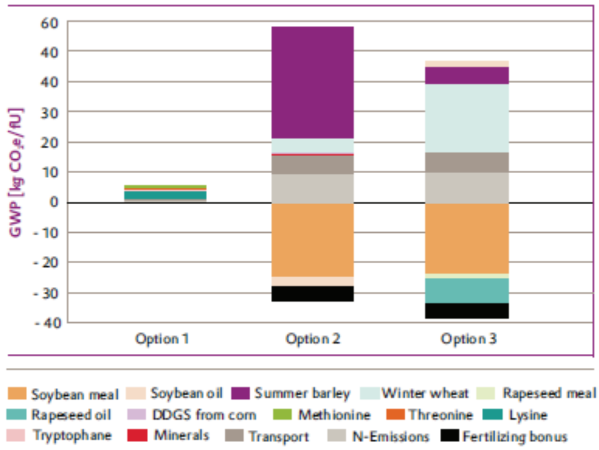


FIGURE 13 - GLOBAL WARMING POTENTIAL GWP100 [CML 2001] OF SWINE PRODUCTION BROKEN DOWN BY INDIVIDUAL CONTRIBUTIONS OF FACTORS

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



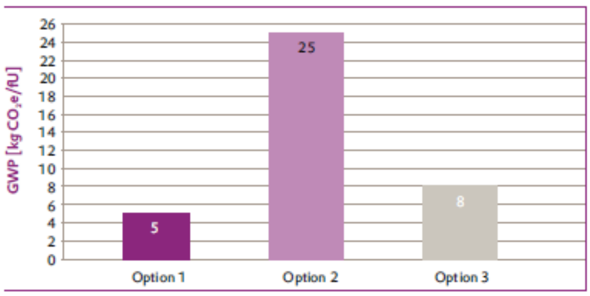
Calculating the reference flows by generating net differences between the feeding options generally leads to negative credits for avoided ingredients and positive contributions by those ingredients included in the individual diet.

The key parameters for the greenhouse gas reduction compared to option 2 are 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



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

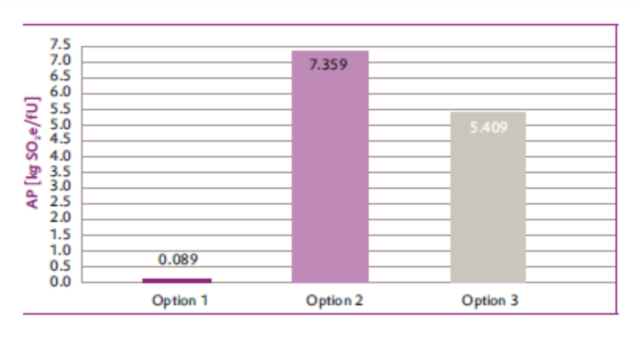


FIGURE 15 - EUTROPHICATION POTENTIAL EP [CML 2001] OF BROILER PRODUCTION

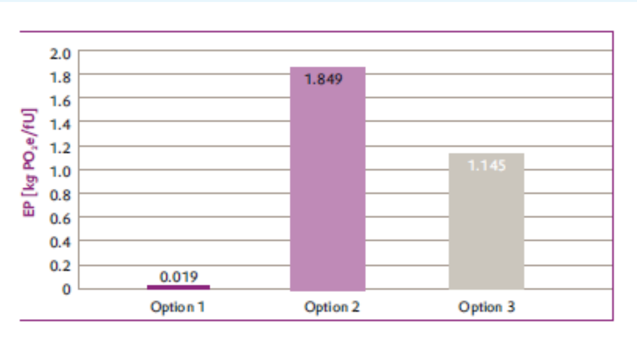


FIGURE 16 - PRIMARY ENERGY DEMAND (PED) OF BROILER PRODUCTION

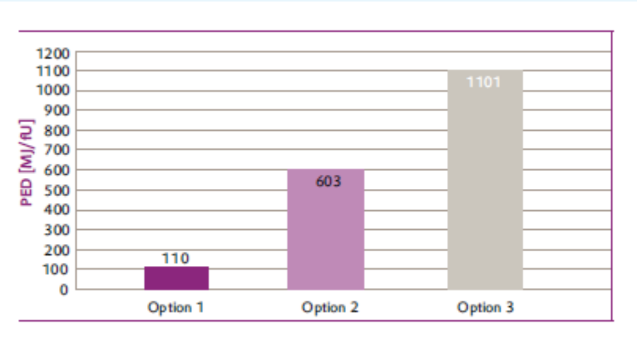
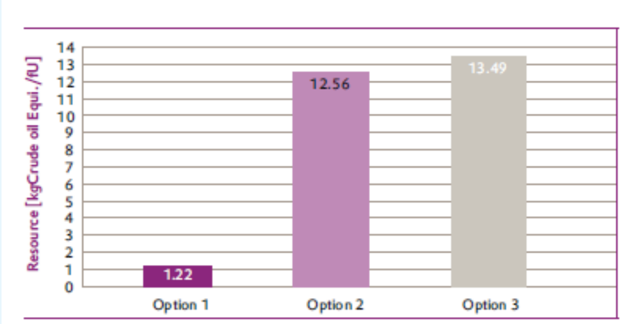


FIGURE 17 - RESOURCE CONSUMPTION OF BROILER PRODUCTION



Emissions	Option 1 (Evonik's solution)	Option 2 (Solution to compare)	Option 3 (Solution to compare)
Acidification potential AP [1] in kg SO_2e/functional unit	0.089	7.359	5.409
Eutrophication potential EP [1] in PO_4e/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

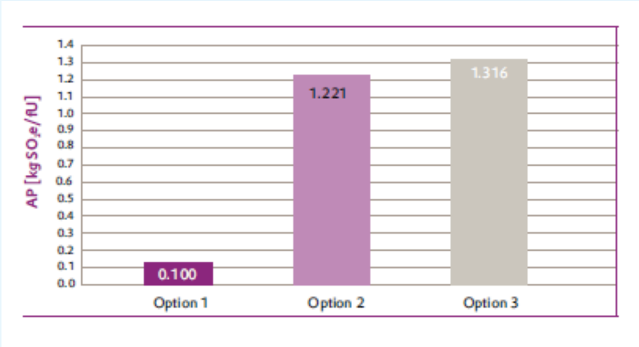


FIGURE 19 - EUTROPHICATION POTENTIAL EP [CML 2001] OF SWINE PRODUCTION

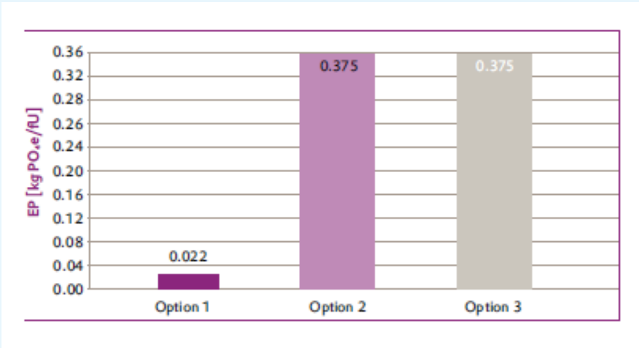


FIGURE 20 - PRIMARY ENERGY DEMAND (PED) OF SWINE PRODUCTION

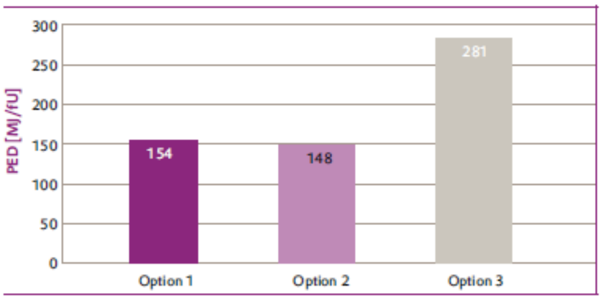
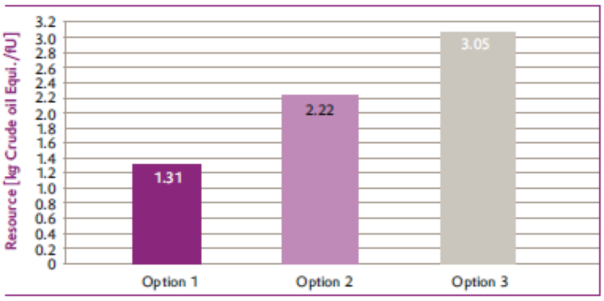


FIGURE 21 - RESOURCE CONSUMPTION OF SWINE PRODUCTION



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.

* 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**.

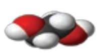
- Process of Bio-MEG production from renewable feedstock /bio route
- Process of Petro-MEG production from petroleum feedstock/petro route

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).

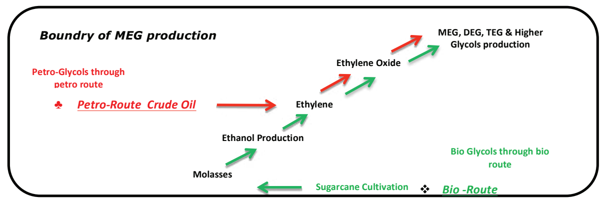
Molecular formula of MEG: $C_2H_6O_2$ Molecular Structure of MEG :



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

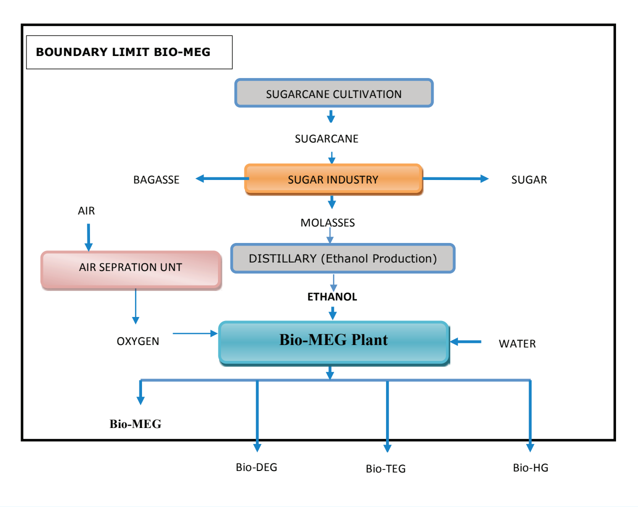
- Process block of Ethanol production
- Process block of air separation unit (Air Separation Unit for Oxygen)
- Process block of Thermal & Electrical Energy production
- Process block of Bio-Glycols (Bio-MEG, Bio-DEG, Bio-TEG and Bio-HG) Production

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.

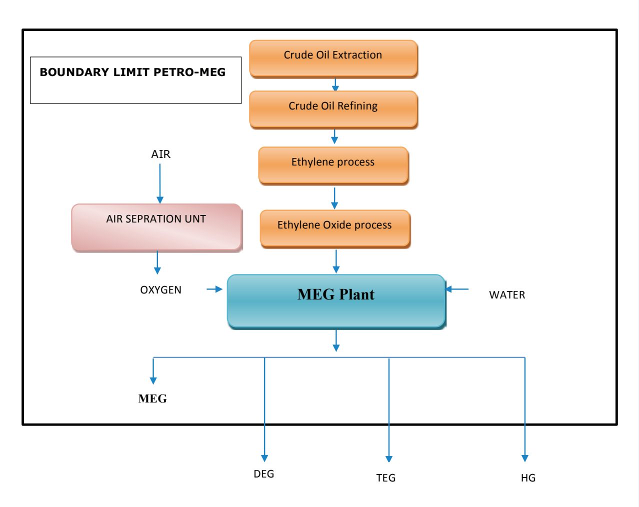
The system boundary of Bio-MEG study covers from cultivation of Sugar cane, transportation of sugarcane to sugar plant, production of molasses, production of ethanol, transportation of ethanol and finally production of Bio-MEG. The study covers the entire life cycle of the Bio-MEG production from cradle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

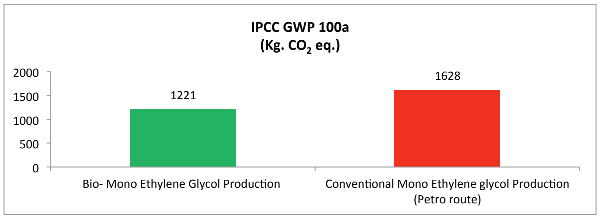
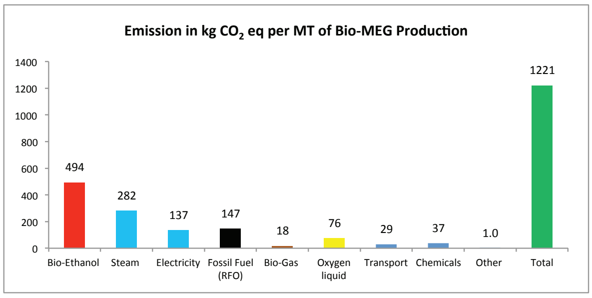


Figure 4 shows the total CO_2 emission generated from Bio-MEG production and from Petro-MEG. The results of the study are presented according to the six Kyoto Protocol gas classifications in CO_2 equivalents for Bio-MEG production at IGL and for Petro-MEG production. These are compared with each other.

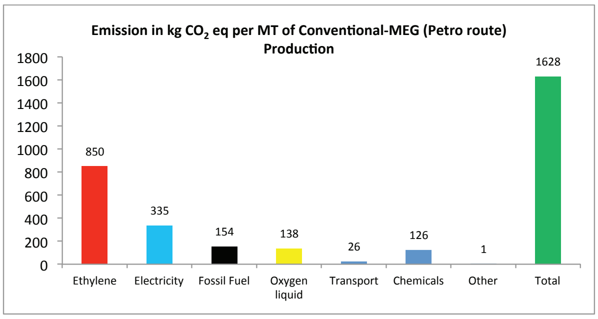
FIGURE 5 - CO_2eq EMISSIONS WHILE MANUFACTURING OF BIO-MEG (CRADLE TO GATE)



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.

TABLE 2 - TABLE SHOWING THE RESULTS OF THE CASE STUDY

Emissions per life cycle phase (CO_2e)	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

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.

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.

11. References

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[7] Molasses for ethanol: the economic and environmental impacts of a new pathway for the lifecycle greenhouse gas analysis of sugarcane ethanol - Anand R Gopal and Daniel M Kammen

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[12] Climate Change 2007: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm

[13] ISO 14040:2006 Environmental Management - Life Cycle Assessment - Principles and Framework

[14] ISO 14044:2006 Environmental Management - Life Cycle Assessment -Requirements and Guidelines

[15] Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis

[16] Energy Efficiency Guide for Industry in Asia – www.energyefficiencyasia.org

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

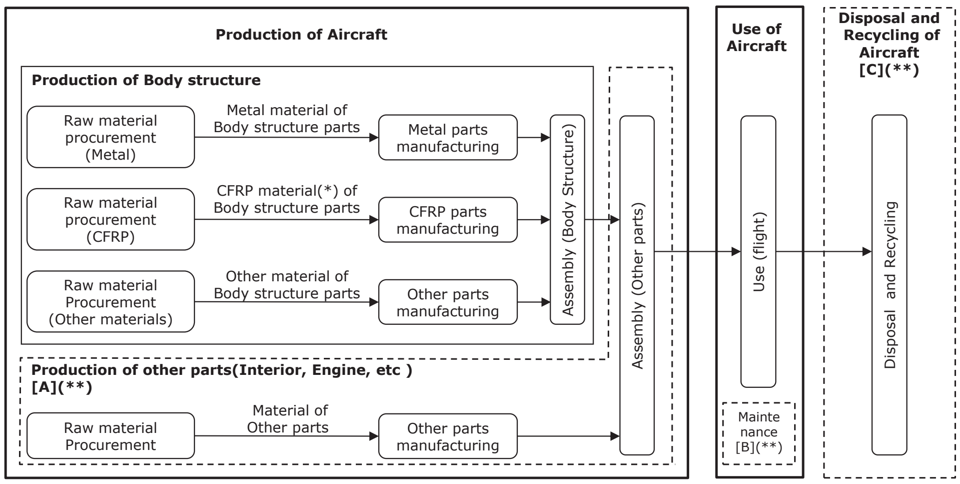
This study starts with a Life Cycle Assessment only focuses on life cycle CO_2 emission as a first step and uses the simplified method. In this study, trade-offs to other environmental impacts are not identified in the screening of LCA.

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

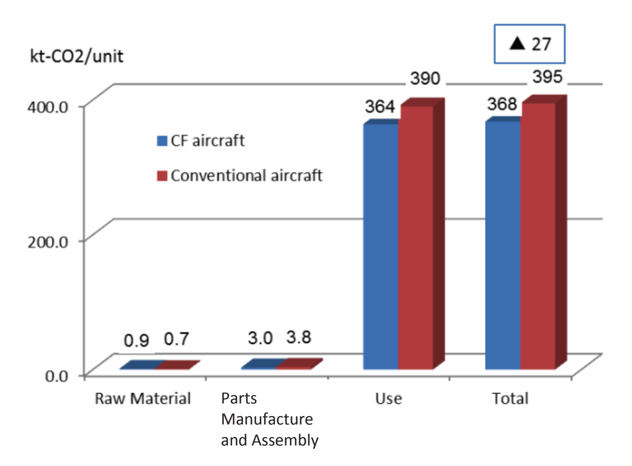
6.1. Avoided emissions

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)

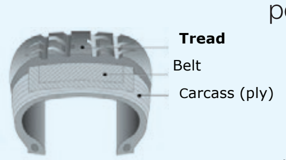
COMMISSIONER AND PERFORMER OF THE STUDY

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.

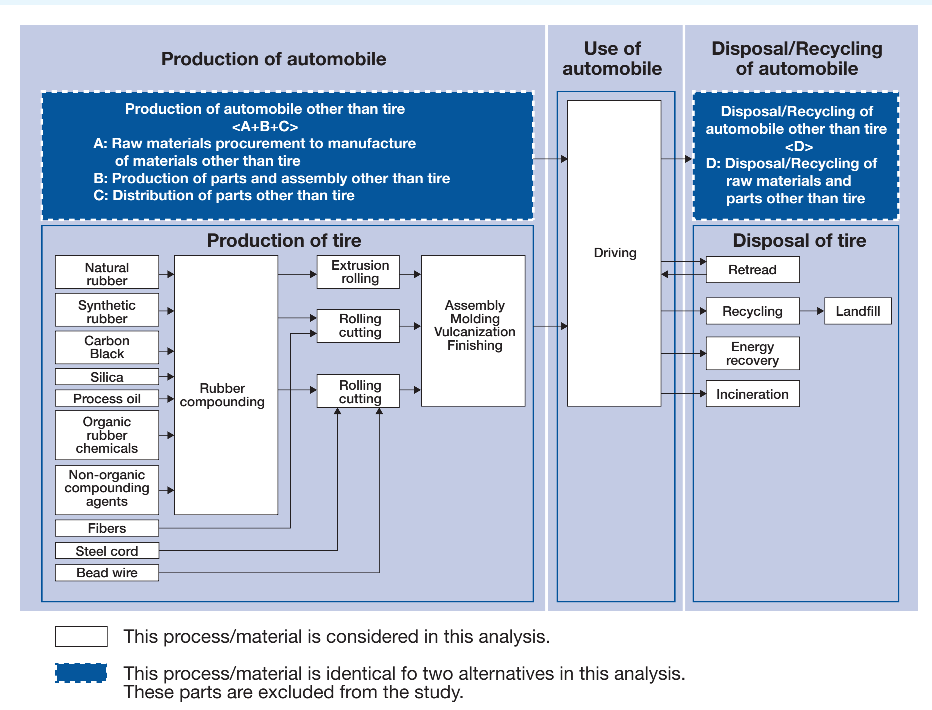
PCR and **TBR** with fuel efficient tires and those of conventional tires are considered to have same process system boundary. At the "production of tire", there are differences in the structure of SBR and composition ratio of chemical products between fuel efficient tires and conventional tires.

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.

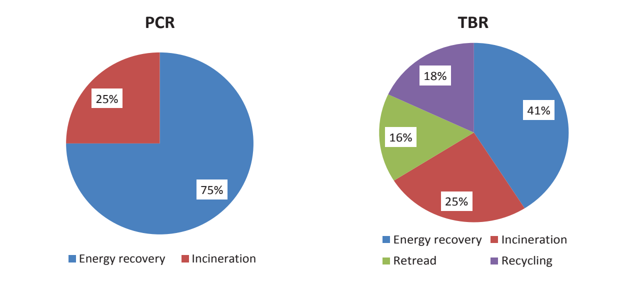
TABLE 2 - AUTOMOBILES' OPERATING CONDITIONS IN THE USE PHASE[2]

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_2e 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

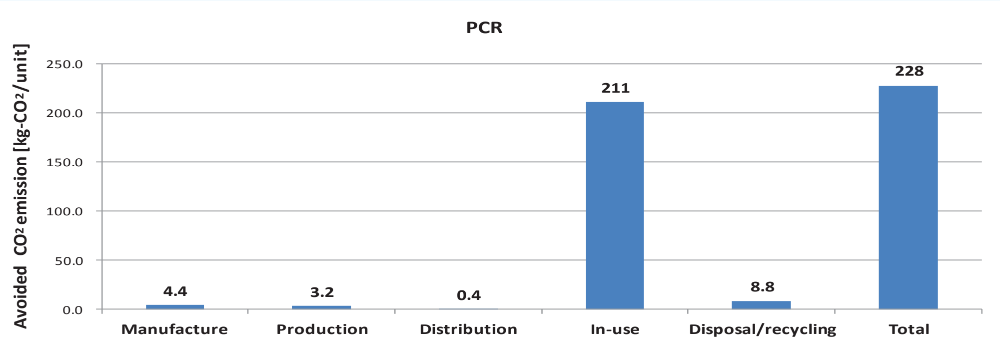
C: CO_2e emissions during the phase of distribution of parts other than tires

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

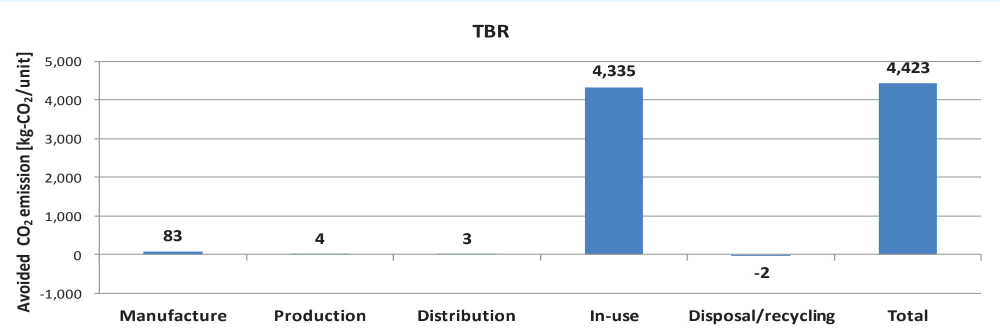
FIGURE 3 - AVOIDED CO_2e EMISSIONS PER THE PCR UNIT



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

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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

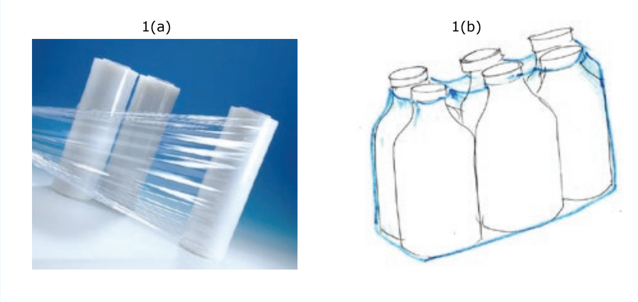
This study is conducted to provide a case study on "A Comparative Lifecycle Assessment on Multilayer Polyethylene Packaging Films" in alignment with the requirements of the document "Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on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

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

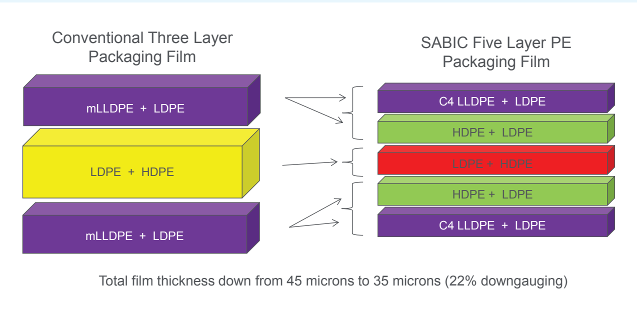
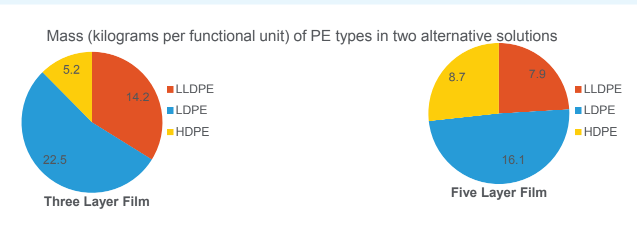


FIGURE 3 - MASS (KILOGRAMS PER FUNCTIONAL UNIT) OF PE TYPES IN TWO ALTERNATIVE SOLUTIONS- THREE LAYER FILM AND FIVE LAYER FILM



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)

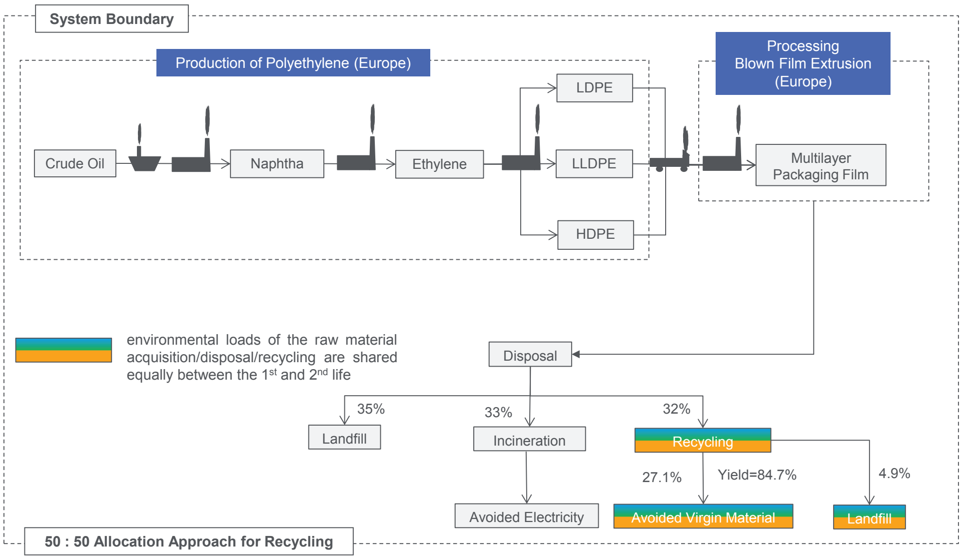
Use phase of the film is outside the system boundary. Use phase of the film comprises of beverage packaging at manufacturing site, transport of the packaged product to retailers, storage, sale, and finally consumption of packaged product.

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 M²)

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.

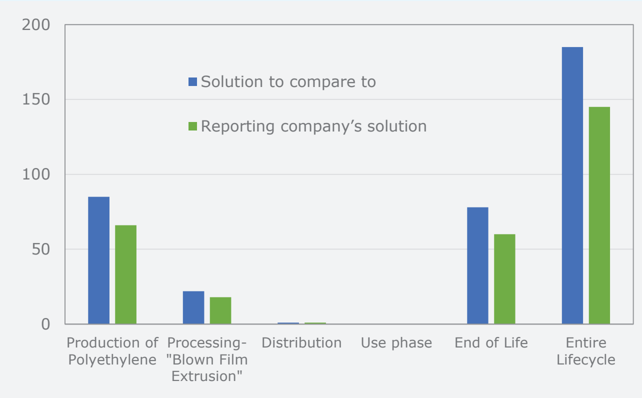
The results show that the avoided emissions per packaging film are dominated by the GHG emissions related to production of polyethylene, end of life disposal, and blown film extrusion process. The impact of distribution is small. Comparing the results of the two alternatives demonstrates that five layer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

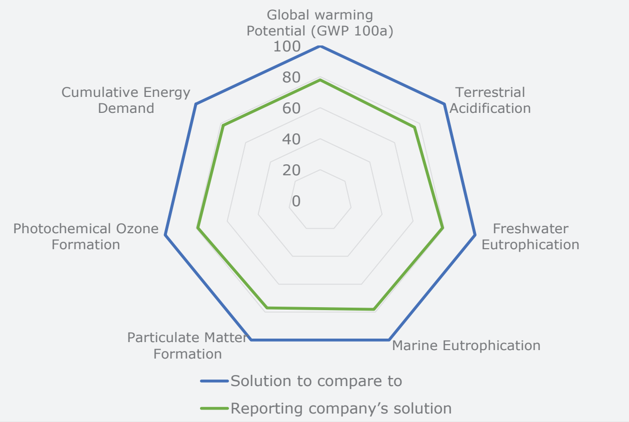
In the goal and scope of the studied it was decided to evaluate seven environmental impact categories to ensure that there are no trade-offs or negative environmental impacts in any of the impact categories. Table 5 below lists all studied impact categories and respective impact assessment methods that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

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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.

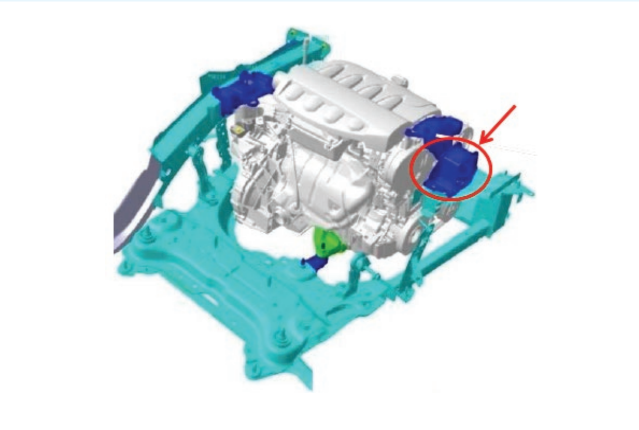
The study demonstrates the contribution of a single small car part, by calculating the reduction in greenhouse gas (GHG) emissions resulting from the use of an engineering plastic (Solvay's Technyl® A 218 V50 BLACK 21 N, named Technyl® in the report) instead of aluminium alloy (Al Si9 Cu3) as material 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

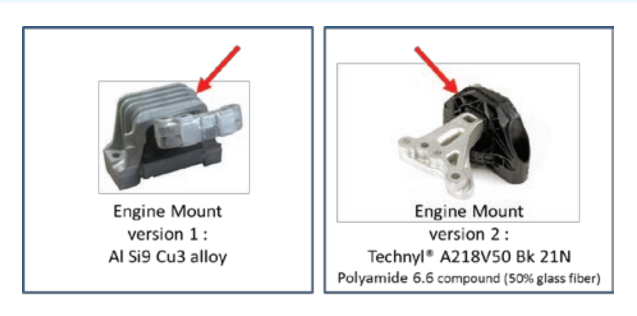
In line with the previous paragraph, the two versions of the Engine Mount Housing are defined as follows:

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

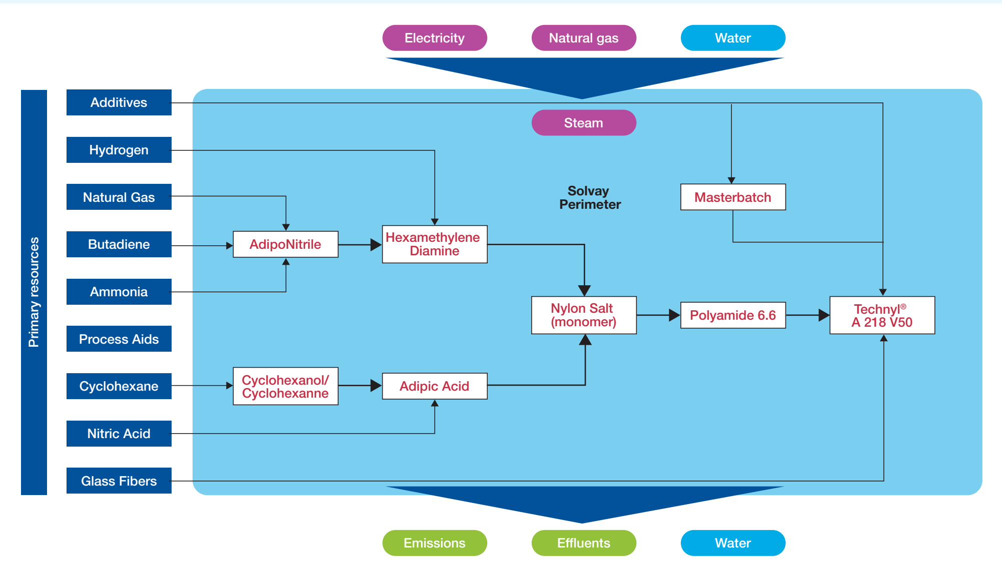
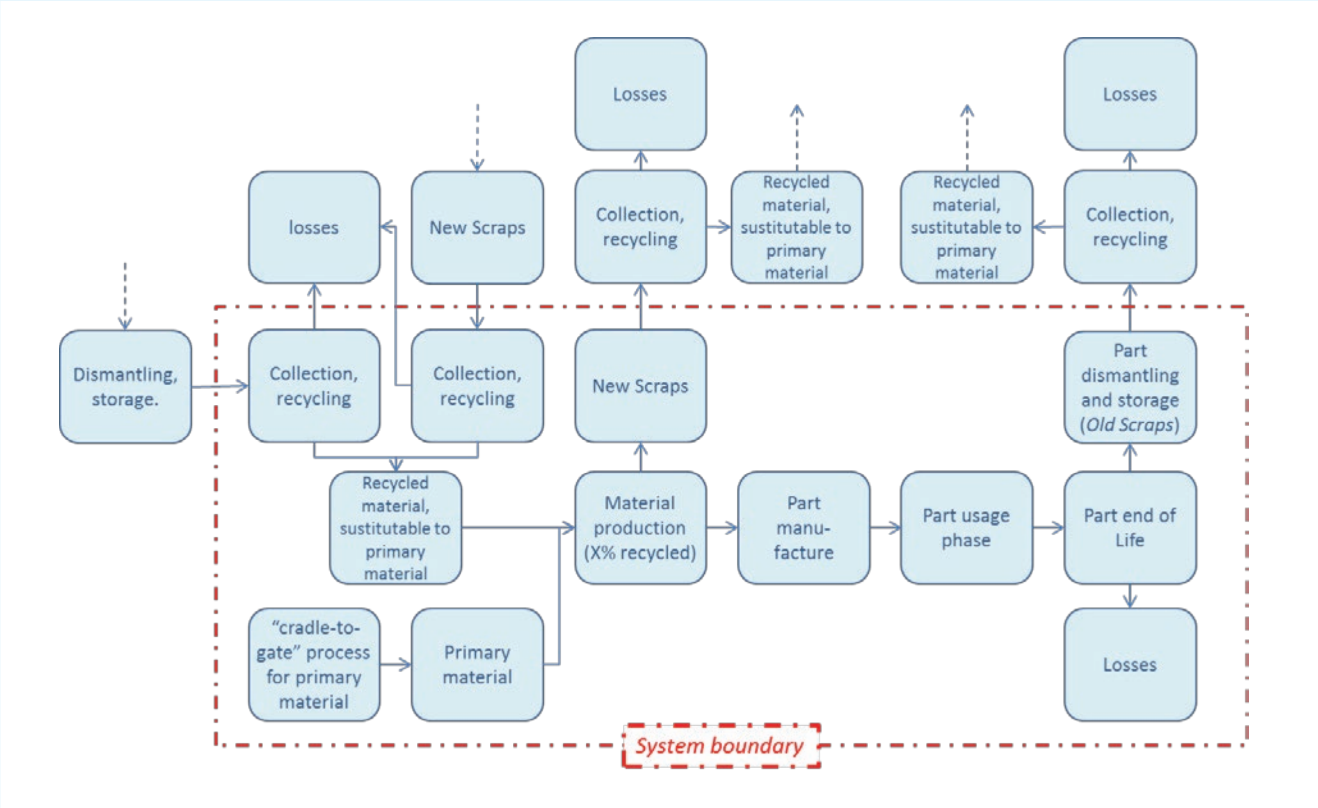


FIGURE 4 - SCHEMATIC REPRESENTATION OF THE SYSTEM BOUNDARIES FOR PARTLY RECYCLED ALUMINIUM



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

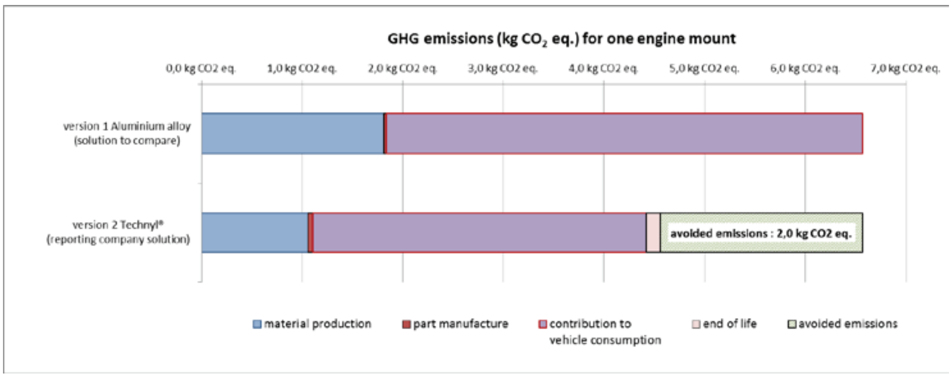


TABLE 6 - AVOIDED EMISSIONS OVER THE ENTIRE LIFE CYCLE OF THE ENGINE MOUNT HOUSING (ACCORDING TO REFERENCE [2] RECOMMENDATIONS FOR THE RELATIONSHIP BETWEEN CAR WEIGHT REDUCTION AND CAR FUEL CONSUMPTION

	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 5,600 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 with 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.

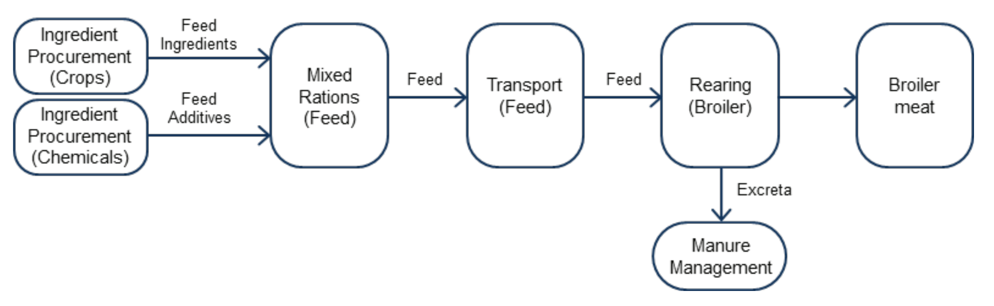
TABLE 1 - OPTIONS OF BROILER FEED

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.

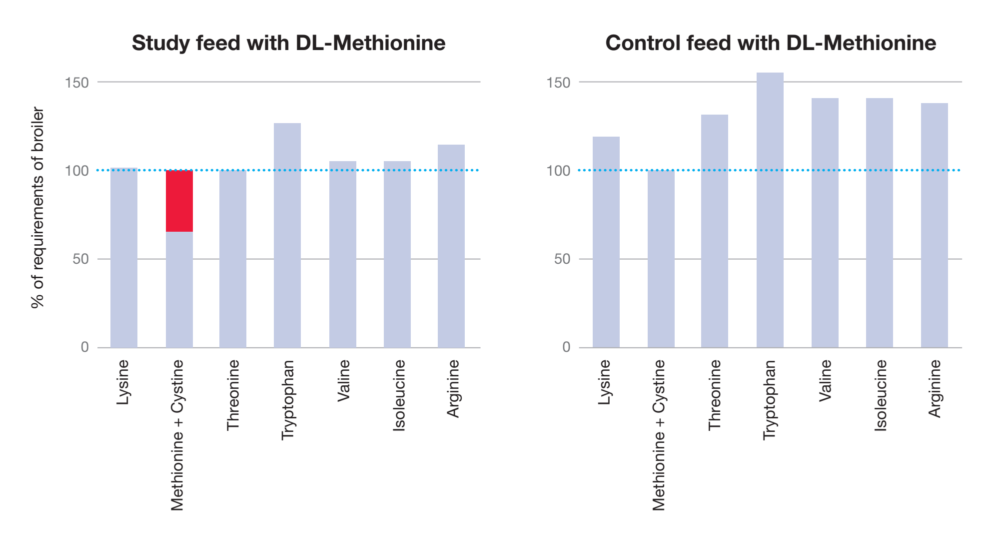
The essential amino acid profiles of the DL-Methionine-supplemented and unsupplemented feed are shown in Figure 2 as percentages of dietary requirements for broilers. Ideally, the feed should contain each of these essential amino acids at levels of 100% of the requirement for adequate production. Both 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

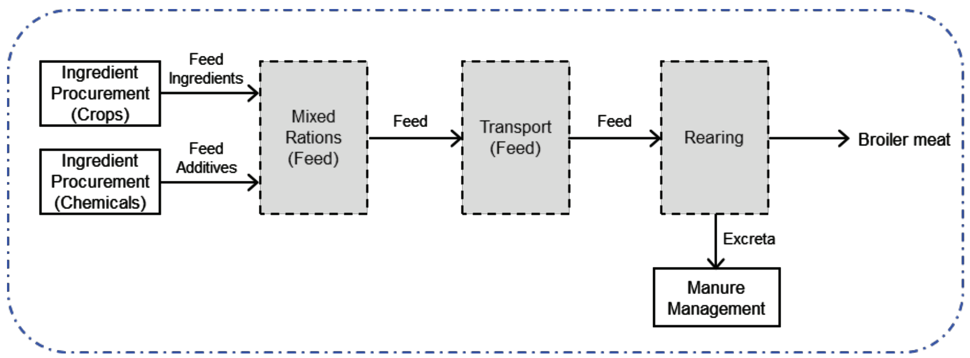
Ingredients	Study feed	Control feed
Corn	58.0%	45.0%
Soybean meal	33.3%	38.3%
Corn gluten meal	0.0%	7.8%
Soybean oil	5.5%	5.9%
Vitamins and minerals	3.0%	3.0%
DL-Methionine	0.2%	0.0%
Total	100.0%	100.0%

4. Boundary setting

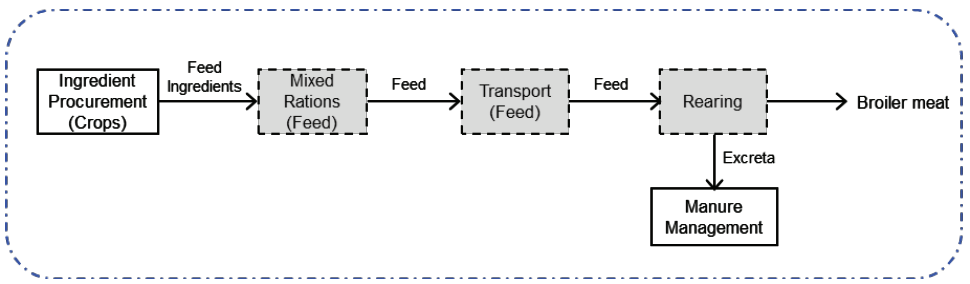
System boundaries defined for the two feed options are shown in Figure 3. This study mainly focused on the ingredient procurement and manure management processes to calculate GHG emissions.

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]

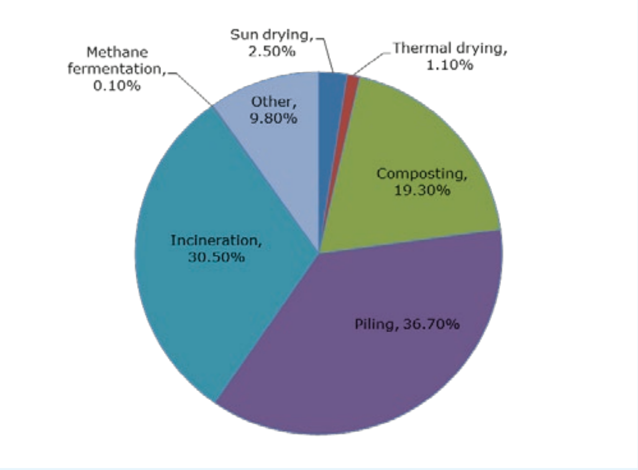


TABLE 7 - N_2O EMISSION COEFFICIENTS BY MANURE PROCESSING METHOD[1] (UNIT: G N_2O-N/G-N)

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 N_2O 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.

Case 10 A comparative study of three fouling control systems for marine vessels

AkzoNobel

COMMISSIONER AND PERFORMER OF THE STUDY

This life-cycle assessment was commissioned by AkzoNobel Marine Coatings, carried out by AkzoNobel Sustainability and reviewed by Quantis.

1. Purpose of the study

AkzoNobel is a world-leading supplier of performance coatings, decorative paint and specialty chemicals for marine applications.

This study was originally commissioned by AkzoNobel Marine Coatings, a part of AkzoNobel supplying coatings for marine applications. The study has been performed by AkzoNobel Sustainability.

Objective of the study is the comparison of three fouling control systems for marine vessels. The goal of this study is to answer the following question:
How big are the greenhouse gas avoided emissions when choosing an Intersleek 1100SR or Intersleek 700 system over an Intersmooth 7460HS system?

This study focuses on three products:

1. Intersleek 1100SR, a biocide-free fluoropolymer fouling control system
2. Intersleek 700, a silicon-based fouling control system
3. Intersmooth 7460HS, a widely used biocide fouling control system

2. Solutions to compare

Marine vessels are used for transportation of goods and people and for leisure activities. The hulls of marine vessels are coated for general protection, for corrosion protection, to prevent fouling and for aesthetic reasons. The energy required to propel a marine vessel through the water is influenced by the hydrodynamics of the vessel which in turn is largely controlled by hull form and propeller design. The choice of coating used on the underwater hull of a vessel can significantly affect the hull performance due to the surface nature of the coating (i.e. how smooth it is) and by how well the coating influences the settlement of fouling organisms.

The settlement of fouling organisms on the underwater hull is well known to adversely influence the fuel consumption of vessels. A layer of slime (multi-culture comprised of bacteria and phytoplankton) is said to result in increased fuel consumption of between 2%-10 %, weed growth in the region of 10%-30%, and animal growth (such as tubeworms or barnacles) in excess of 40%.

The fouling control systems compared in this study are Intersleek 1100SR SPC, Intersleek 700 and Intersmooth 7460HS. Each individual fouling control system consists of layers of different coatings all of which perform different functions; together they are referred to as the "scheme".

All fouling control schemes use Intershield 300 to protect the underlying steel substrate of the vessel. Intershield 300 is a high quality pure epoxy coating with aluminium to prevent corrosion of the steel substrate and is compliant with the International Maritime Organisation (IMO) Performance Standard for Protective Coatings (PSPC). To ensure good inter-coat adhesion within the schemes, each fouling control system has its own unique tie-coat. A tie-coat is a coating specifically designed to allow two opposing types of coatings to stick together within the scheme as a whole. For the Intersleek systems (both Intersleek 700 and 1100SR), the tie-coat is Intersleek 737, whereas for the Intersmooth 7460HS system, the tie-coat is Intergard 263. The main difference in the three fouling control systems occurs in the final coats, which are subjected to the general environment through which the vessel trades. The final coats are Intersmooth 7460HS, Intersleek 757 (for the Intersleek 700 scheme) and Intersleek 1100SR (for the Intersleek 1100SR scheme). It is the final coat in the scheme, which controls both the control of fouling growth and influences the hydrodynamic water flow passing the hull of the vessel.

Figure 1 shows the scheme in a diagrammatic form. The different layers within the schemes are applied at set thicknesses according to their function and the vessel's operational profile. The schemes are shown in tables 6 and 12. The content of Volatile Organic Compounds (VOC) and volume solids of each of the coatings are properties which together with the layer thicknesses determine the amount of paint needed for each vessel (see table 2).

Both the Intersleek 700 and Intersleek 1100SR systems work through a completely non-toxic mechanism, as they do not contain biocides. Both coatings, when first applied to the underwater hull of a vessel, form a smooth surface layer with Intersleek 700 being slightly rougher than Intersleek 1100SR. The low surface profile of both coatings helps to minimise the effect on the hydrodynamics of the vessel, which results in lower fuel consumption (when compared to Intersmooth 7460HS). Both systems are curing products, which mean that when they are applied to the underwater hull, the components within the systems react together to form a cross-linked polymer matrix. Once cured, the paint systems do not change their form or react with seawater and so the initial smooth surface layers are maintained.

Intersleek 700 controls the growth of fouling organisms by creating a hydrophobic surface to which organisms such as barnacles have difficulties adhering to. Most fouling organisms excrete a protein-glue to attach to a surface and hydrophobic surfaces make it difficult for that glue to spread and create good adhesion between the surface and the organism itself. As Intersleek 700 does not contain any biocides, fouling organisms will attach weakly if a vessel is static but once the vessel starts to operate, the friction of the water on the outer hull of the vessel will remove the fouling organism.

Intersleek 1100SR works on a similar principle but instead of creating a pure hydrophobic system, the surface of this coating can be described as being amphiphilic, i.e. a mixture of hydrophobic and hydrophilic. The surface of Intersleek 1100SR is a microscopic mosaic of hydrophilic and hydrophobic domains that effectively “confuse” settling larvae of fouling organisms and make the surface unattractive for them to grow. On Intersleek 700, organisms can only create a weak adhesion to the surface and are easily removed by the vessel moving through water.

For the Intersmooth 7460HS the fouling growth is controlled through the slow dissolution of the paint matrix which undergoes a reaction with seawater ions. At the same time, biocides, dispersed within the body of the coating, are released into the local environment. The biocides control the growth of fouling organisms through basic deterrence by making the surface unsuitable for settlement but also by creating a local toxic effect.

Studied system, data and assumptions

The study assumed that the vessel would be constructed at a European new construction facility (Odense was selected due to the capability there to build the largest vessels) and repaired in the Middle East (Dubai was selected as the highest throughput maintenance yard in that region). This was so that transport distances could be calculated and factored into the study. However, those transport factors were expected to have limited effect on the results of the study and it is therefore reasonable to assume that construction and maintenance of a vessel anywhere in the world be covered in this study.

Since this study takes the life-cycle perspective of the fouling control systems it includes all stages from the extraction of natural resources through the different refining stages to the final generation of all the activities and products depicted in figure 2. This means that the environmental interventions caused by the grey shaded activities, and the activities upstream and downstream from these, are included as well. The environmental influence caused by the production and future demolition of machines, industrial plants and infrastructure are however not included. The rationale for this is that based on previous studies it has been concluded that these activities’ impact on the overall impact of the system will be very small and not influence the result.

Below, the system is described further regarding the numbered unit processes. In figure 2 they are depicted in terms of activities and flows required. Assumptions and cut-offs are made to complete the modelling. Table 3 (confidential information: not included in this report) summarises all the technical and elementary flows included in this assessment, and the environmental impacts that are associated indirectly to the technical flows[1] via industrial activities, or directly to the elementary[2] flows. The magnitude of all flows in has been provided by AkzoNobel Marine Coatings and is based on real case observations and on experience from working closely with the shipping industry. The magnitudes specified for the flows represent a container ship when operating 15 years. Table 4 (confidential information: not included in this report) presents the costs that were applied for different products and services. For information regarding sources for inventories for the activities in scope, contact AkzoNobel Sustainability.

FIGURE 1 - THE DIFFERENT LAYERS OF THE COMPARED COATING SYSTEMS.

	Intersmooth 7460HS	Intersleek 700	Intersleek 1100SR
5	Intersmooth 7460HS		
4	Intersmooth 7460HS	Intersleek 757	Intersleek 1100SR
3	Intersmooth 7460HS	Intersleek 737	Intersleek 737
2	Intergard 264	Intershield 300	Intershield 300
1	Intershield 300	Intershield 300	Intershield 300
0	Hull	Hull	Hull

1 A technical flow is a flow of a material or energy carrier that is kept within the techno sphere
2 An elementary flow is a flow of a material or energy carrier which is either brought from nature into the techno sphere, or emitted from the techno sphere to nature

3. Function of the product/ application

Functional unit

The study takes the ship owners' perspective and focuses on how the choice of the fouling control system for the underwater hull influences the carbon dioxide emissions of a vessel. The function of the study is therefore the movement of a vessel, and the functional unit defines the distance travelled by a vessel of a certain weight (including cargo, personnel, etc.) and hull form during a certain period.

The vessel classes considered in this study are Bulk Carrier, Crude Oil Tanker, Container Ship, Liquid Natural Gas carrier (LNG), Roll-On Roll-Off ferry (Ro-Ro) and Cruise Liner. Each vessel class differs in its operational profile – speed, activity (time in port versus that travelling), fuel consumption and dry-docking cycle (30 or 60 months).

Table 1 quantifies the functional unit for the different vessel classes. For the Containership class the functional unit is:
"The travel of 2 365 200 nautical miles of a 300 meter long container ship, with an underwater area of 12 000 m^2 and a loading capacity of 70 000 dead weight tonne, during 15 years of operation, including 3 maintenance cycles."

The actual load is an average for the trading of the particular vessel. Tankers, bulkers and LNG all trade roughly 75% loaded, 25% in ballast (loaded taking cargo to destination, ballast returning to loading port). Ferries, cruise and container ships all roughly trade at the same level. Ferries and Cruise have no significant change in draft between loaded and unloaded due to the relative weight of the cargo being so much smaller than the weight of the ship. Container ships do have some ballast time but the majority of time they are ferrying around containers from port to port loading and unloading at each port, hence generally remaining the same draft.

TABLE 1 - DEFAULT PROPERTIES FOR THE DIFFERENT VESSEL CATEGORIES.

		Bulker 6K SMM	Tanker 6K SMM	Container 13K SMM	Container 10K SMM	LNG 12K SMM	Ro-Ro 9K SMM	Cruise 11K SMM
Size	Dead Weight Tonne	70 000	300 000	67 000	67 000	75 000	16 000	45 000
Speed	Knots	13	11	20	16	19	19	23
Underwater Area	Square Metres	10 000	19 000	12 000	12 000	12 000	3 000	5 000
Fuel Consumption	Tonnes/day	35	100	150	120	150	20	60
Fuel Consumption	Tonnes/km	0.061	0.205	0.169	0.169	0.178	0.024	0.059
Activity	Percent	73%	80%	90%	90%	90%	70%	70%
Fuel Consumption	Tonnes/year	9 326	29 200	49 275	39 420	49 275	5 110	15 330
Drydock Cycle	Years	2.5	5	5	5	2.5	2.5	2.5
Seamiles	Seamiles/month	6 928	6 424	13 140	10 512	12 483	9 709	11 753
Rounded Seamiles		6 000	6 000	13 000	10 000	12 000	9 000	11 000
Length of vessel	Metres	100	350	300	300	250	160	250

TABLE 2. VOLATILE ORGANIC CHEMICALS (VOC) CONTENT AND VOLUME SOLIDS OF THE PAINTS.

	INTERSHIELD 300	INTERGARD 263	INTERSMOOTH 7460HS SPC	INTERSLEEK 737	INTERSLEEK 757	INTERSLEEK 1100SR
VOC content w/w %	30%	31%	30%	38%	16%	23%
Volume solids v/v%	60%	64%	54%	56%	72%	74%

3.1 Service life of the solution

The typical commercial cycle of a ship is that between every 10 and 15 years in-service, the underwater hull is completely sand-blasted and all paint completely removed. For this study, it has been assumed that the coatings are completely removed after 15 years.

3.2 Time and geographic reference of the study

This study was conducted in 2014 and is valid for all ships painted with the three materials, respectively. Since the product life is 15 years on the substrate the study and its results are valid until at last 2029.

Reference periods for the data used varies dependent of the individual sources. However, future updates of applied data by e.g. suppliers, industry associations or database providers are not expected to affect the study's overall results significantly.

The study is based and focused on state-of-the-art marine coating technologies as applied today and it does not include scenarios to project impacts of potential future coating systems.

The coatings are manufactured by AkzoNobel Marine Coatings in Felling, United Kingdom, and in Damman, Saudi Arabia. Coatings of the Intersleek range are produced in Felling only, whereas all of the other coatings are produced in Felling for the initial application to the vessel in Denmark and in Damman for the maintenance.

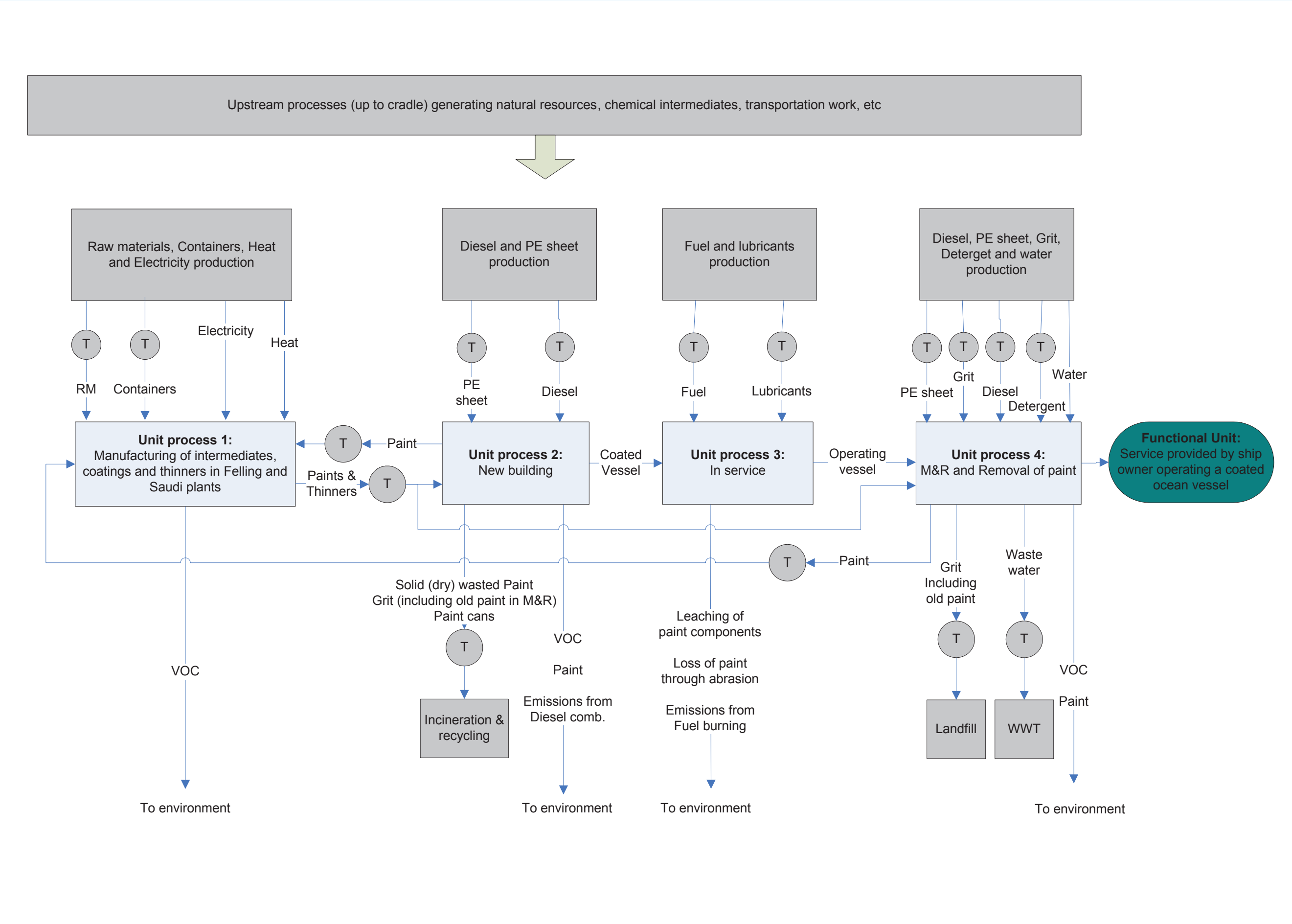
Unit process 1: Manufacturing of coatings and thinner in Felling and Saudi plants

Intersleek 737, 757 and 1100SR are three component coatings meaning that each "unit" of paint is comprised of three containers of individual components. Intershield 300 and Intergard 263 are two component coating (hence two containers) and Intersmooth 7460HS is a single component coating (one container).

The individual components in each paint are produced by dispersing/mixing a set of raw materials according to defined process sequences and recipes. A small amount of raw materials is lost as VOC emissions and as general yield loss (e.g. raw material residues in original containers). Once manufactured, the finished goods are filled into relevant containers of varying sizes and transported to the appropriate location. The yield losses, heat and electricity demand in the manufacturing and the transportation work required for the distribution of the both raw materials and finished goods are primary data provided by AN M&PC.

4. Boundary setting

FIGURE 2 - FLOWCHART OF THE STUDIED SYSTEM AND THE PROCESSES REQUIRED TO PRODUCE THE FUNCTIONAL UNIT AND WHICH THE CHOICE OF COATING SYSTEM INFLUENCES.



Altogether, both fouling control systems consist of 60 raw materials some of which are pure substances and others homogeneous mixes of several different substances. Some of the base polymers that go into the coatings are also produced by AkzoNobel Marine Coatings.

Unit process 2: New building of vessel

The first application of the coating systems at new building of the vessel is assumed to take place in Odense, Denmark, according to the schemes presented in table 6. The vessel is assumed to be in a fully blasted condition with steel ready to be painted. This is only realistic for a small vessel as larger vessels are constructed from pre-fabricated blocks with application of the coatings taking place at various stages in the construction of the vessel. However, due to the complexity of the building process it was felt that this was a fair assumption to make.

For the multi component coatings the different parts are mixed before application. The coatings are assumed to be applied by a human work force of six people with airless spray guns. One spray gun, pump and cherry picker is assumed for each sprayer. The pumps are of 68:1 ratio and the input pressure is 80 pounds per square inch (psi).

The spray pump compressor consumption and the cherry picker consumption are considered to be diesel at 6 litres/hour and 10 litres/hour respectively.

For the application of the Intersleek paints it is a requirement for the above water parts of the vessel to be protected from overspray with a plastic sheet (assumed to be polyethylene) around two metres wide which is attached at the waterline.

The amount of paint applied (see table 7) is calculated from the required dry film thickness, volume solids of the coating and an application loss factor of 30%. The assumption is that 25% will be lost to the environment through overspray and 5% will be lost in tins as paint residue or in spray lines. A small amount of thinner is also used as a cleaning agent for the spray equipment.

All solvents in the paints that are not left in containers or captured are assumed to be emitted to the environment as VOC emissions without prior treatment. All the containers and the paint leftovers are sent as hazardous waste to a waste treatment facility where the wet paint is separated from the containers and incinerated with heat recovery. The steel in the steel containers is recovered and recycled.

TABLE 3 - NEW BUILDING SCHEMES – DRY FILM THICKNESS IN MICRONS

		Bulker 6K SMM	Tanker 6K SMM	Container 13K SMM	Container 10K SMM	LNG 12K SMM	Ro-Ro 9K SMM	Cruise 11K SMM
Intersmooth 7460HS SPC								
Intershield 300	microns	150	150	150	150	150	150	150
Intergard 263	microns	100	100	100	100	100	100	100
Intersmooth 7460HS SPC	microns							
Intersmooth 7460HS SPC	microns				Confidential data			
Intersmooth 7460HS SPC	microns							
TOTAL Intersmooth 7460HS SPC	*microns*							
Intersleek 700, 900, 1100SR								
Intershield 300	microns	150	150	150	150	150	150	150
Intershield 300	microns	150	150	150	150	150	150	150
Intersleek 737	microns	100	100	100	100	100	100	100
Intersleek 1100SR	microns	150	150	150	150	150	150	150

TABLE 4 - PAINT VOLUMES, IN LITRE, FOR THE APPLICATION, INCLUDING LOSS OF PAINT.

Confidential data

Unit process 3: In service

The in service stage of the lifecycle refers to the operation of the vessel and the global transportation of goods and people. The main activity during the in service stage, which may be influenced by the choice of coating system, is the vessel engine operation with its corresponding fuel consumption. Different vessels require different amounts of fuel, mainly dependent on the size and speed of the vessel during in service. Table 8 shows the fuel consumption that has been estimated for the different vessels when coated with either of the schemes. It also illustrates the assumed speed, activity and transportation distance related to the specified fuel consumption.

The Intersleek coating systems improves several aspects of coating performance, which have an influence on the fuel consumption, compared to the Intersmooth 7460HS system. Examples are lower surface hull roughness, better coefficient of friction and better foul release properties, which, for the Intersleek 1100SR system leads to predicted reduction in fuel consumption of 6% but with actual vessels showing up to 9% reductions relative to the Intersmooth 7460HS system.

As a starting point for this study, fuel reductions of 4% and 6% relative to Intersmooth 7460HS were assumed for Intersleek 700 and Intersleek 1100SR respectively. This assumption is backed up by independent studies at Newcastle University in the UK (see [1] and [2]) as well as ship operator testimonies on the performance of these coatings (K Line testimony of 8%, Mercator testimony of 6% for part vessel and 9% for full vessel).

In addition to fuel, the vessel engine also consumes lubrication oil for the smooth operation of moving parts. The amount of lubricant oil that is needed is assumed to be proportional to the work performed by the engine (see [3]), and hence also to the amount of fuel burned.

During the in service stage, coating is lost from the hull through mechanical forces (abrasion, general wear-and-tear).

Vessels have to be routinely dry-docked at regular intervals for class inspection (every five years for the first fifteen years as a minimum) as well as for maintenance and repair of the fouling control system. Different vessel categories have different docking cycles. For this study, the dry-docking records from the International Paint Dataplan system were analysed to assess the docking cycle for each class of vessel (see table 11 for dry-dock schematic). Table 9 shows the share of the underwater area that is estimated to be damaged during in service.

As an absolute worst case evaluation all paint on this area including the underlying anticorrosive and tie-coat is assumed to be lost to the marine environment. In practice, losses to the marine environment will vary from region to region. The estimates used for each class of vessel come from actual dry-docking experience for each vessel and coating type. Typically, Intersleek systems (both 700 and 1100SR) show lower levels of damage when compared to Intersmooth 7460HS.

Intersmooth 7460HS coating is a class of biocidal antifouling known as self-polishing copolymers (SPC); these paints are designed to dissolve away into the environment during use, so significant quantities of this paint is also lost to the marine environment.

Furthermore, it has been assumed that some coating components will also leach from the Intersleek coating systems at very low levels.

The total amount of paint that is emitted to the marine environment during the in-service period is therefore assumed to be equal to the amount of paint (dry) that has to be applied during maintenance and repair plus the amount of paint that is lost between the last maintenance and repair and removal (assumed to be the same as during service interval M&R 3 – M&R 4) plus components leaching out (and not accounted for in the M&R volumes).

The only raw materials with any specific leaching factors are as follows: all components of Intersmooth 7460HS (including acrylic copper copolymer, zinc pyrithione and cuprous oxide), methylphenyl siloxane in Intersleek 757 and Fluorolink E10H in Intersleek 1100SR (see table 10 for leaching factors for these components).

The leaching factors for the two components in the Intersleek paints are based on estimates from initial leaching evaluations rather than absolute scientific data.

The components that make up the acrylic copper copolymer used in Intersmooth 7460HS are released as sodium naphthenate, copper chloride and a sodium salt of the acrylic copolymer. For the marine eco-toxicity potentials assigned to these components see section “Environmental Impact and Eco-Efficiency Assessment”.

All the carbon in the emitted paint is assumed to be oxidized to fossil CO_2. In addition to the CO_2 emissions, the toxicity of the emitted paints is also considered.

TABLE 5 - FUEL CONSUMPTION, AND OTHER PARAMETERS, FOR THE SIX DIFFERENT VESSEL CLASSES WHEN COATED WITH THE INTERSLEEK 1100SR COATING SYSTEM.

		Bulker 6K SMM	Tanker 6K SMM	Container 13K SMM	Container 10K SMM	LNG 12K SMM	Ro-Ro 9K SMM	Cruise 11K SMM
Fuel Consumption	Tonnes/day	35	100	150	120	150	20	60
Activity	Percent	73%	80%	90%	90%	90%	70%	70%
Fuel Consumption	Tonnes/year	9 326	29 200	49 275	39 420	49 275	5 110	15 330
Drydock Cycle	Years	2,5	5	5	5	2,5	2,5	2,5
Seamiles	Seamiles/month	6 928	6 424	13 140	10 512	12 483	9 709	11 753

TABLE 6 - PERCENT OF THE UNDERWATER AREA THAT IS DAMAGED DURING IN SERVICE AND NEEDS TO BE REPAIRED DURING MAINTENANCE AND REPAIR.

		Bulker 6K SMM	Tanker 6K SMM	Container 13K SMM	Container 10K SMM	LNG 12K SMM	Ro-Ro 9K SMM	Cruise 11K SMM
Intersmooth 7460HS scheme								
Drydock 1	1	10	15	20	20	10	10	7
Drydock 2	2	30	30	40	40	25	20	15
Drydock 3	3	40	100	100	100	35	30	25
Drydock 4	4	50				50	40	35
Drydock 5	5	100				100	100	100
Intersleek 700, 900, 1100SR scheme								
Drydock 1	1	5	5	10	10	5	5	5
Drydock 2	2	15	15	20	20	10	10	10
Drydock 3	3	5	100	100	100	5	5	5
Drydock 4	4	15				15	15	15
Drydock 5	5	100				100	100	100

TABLE 7 - LEACHING FACTORS FOR COMPONENTS LEACHING TO THE MARINE ENVIRONMENT DURING IN SERVICE. THE LEACHING FACTORS COMMUNICATE HOW MUCH OF THE COMPONENTS IN THE PAINT THAT IS DISSOLVED LEACHES TO THE ENVIRONMENT.

Confidential data

Unit process 4: Maintenance, repair and removal of paint

The maintenance, repair and removal of the fouling control systems is assumed to take place in Dubai according to the dry dock schematic in table 11. At maintenance and repair the underlying coats are only applied on the damaged areas whereas the top coats are applied over the whole underwater area, according to the schemes in table 12.

Before application, the vessel is washed and the areas selected for repair prepared through grit blasting. A vessel already coated with the Intersmooth 7460HS scheme will be washed once throughout the docking, whereas a vessel coated with either Intersleek 700 or Intersleek 1100SR schemes will be washed two times, the second wash comprising a detergent wash. For washing, it has been assumed that 5 litres of water per square meter will be needed per wash and 60 litres of detergent per detergent wash. The grit blasting is assumed to be carried out by 10 blasters and 6 cherry pickers at a rate of 50 m^2/man/hour. The grit consumption is 45 kg/m^2.

Application of the repair scheme is considered in the same way as for application at the new construction stage.

The amount of paint applied (see table 13) is calculated from the required dry film thickness, volume solids of the coating and an application loss factor of 30%. The assumption is that 25% will be lost to the environment through overspray and 5% will be lost in tins as paint residue or in spray lines. A small amount of thinner is also used as a cleaning agent for the spray equipment.

All solvents in the paints that are not left in containers or captured are assumed to be emitted to the environment without prior treatment. All the containers and the paint leftovers are sent as hazardous waste to a waste treatment facility where the wet paint is separated from the containers and incinerated with heat recovery.

The grit and old paint are considered to be sent to landfill. From the off-gases of the landfill (mostly methane) energy in the form of electricity is recovered and credit is given for avoided emissions from Saudi-Arabian country grid electricity.

The impact of this credit is insignificant in size regarding the full life-cycle impacts considered in this study. The wash water is assumed to be sent to a municipal waste water facility via a public sewage system.

The typical commercial cycle of a ship is that between every 10 and 15 years in-service, the underwater hull is completely blasted and all paint removed. For this study it has been assumed that the coatings are completely removed after 15 years. Before removal, the vessels are washed in the same way as during maintenance and repair. The paint is then removed through grit blasting. The wash water and the grit and old paint are assumed to be treated the same way as during maintenance and repair.

TABLE 8 - DRY DOCK SCHEMATIC.

	Service Year															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bulker	NB			Drydock 1			Drydock 2			Drydock 3			Drydock 4			Remove
Tanker	NB					Drydock 1					Drydock 2					Remove
Container	NB					Drydock 1					Drydock 2					Remove
LNG	NB			Drydock 1			Drydock 2			Drydock 3			Drydock 4			Remove
Ro-Ro	NB			Drydock 1			Drydock 2			Drydock 3			Drydock 4			Remove
Cruise	NB			Drydock 1			Drydock 2			Drydock 3			Drydock 4			Remove

TABLE 9 - MAINTENANCE SCHEMES SHOWING DRY FILM THICKNESS OF ALL PAINT LAYERS

			Bulker 6K SMM	Tanker 6K SMM	Container 13K SMM	Container 10K SMM	LNG 12K SMM	Ro-Ro 9K SMM	Cruise 11K SMM
Intersmooth 7460HS SPC									
Intershield 300	touch-up	microns	150	150	150	150	150	150	150
Intergard 263	touch-up	microns	100	100	100	100	100	100	100
Intersmooth 7460HS SPC	full coat	microns	Confidential data						
Intersmooth 7460HS SPC	full coat	microns							
Intersmooth 7460HS SPC	full coat	microns							
Total Intersmooth 7460HS SPC		*microns*							
Intersleek 700, 900, 1100SR									
Intershield 300	touch-up	microns	150	150	150	150	150	150	150
Intershield 300	touch-up	microns	150	150	150	150	150	150	150
Intersleek 737	touch-up	microns	100	100	100	100	100	100	100
Intersleek 700, 900, 1100SR	full coat	microns	100	100	100	100	100	100	100

TABLE 10 - PAINT VOLUMES, IN LITRES, FOR THE MAINTENANCE AND REPAIR, INCLUDING LOSS OF PAINT.

Confidential data

4.1 Data quality

Suppliers were contacted for manufacturing data for all the raw materials that constituted more than 1% of the overall coating weight or raw material cost. However, inventories could only be established for 9 raw materials based on supplier responses. Raw materials from respondents represent however 42% of the total raw material weight required for producing all paints needed for the Intersleek schemes and 39% of all the paint required for production of all paints needed for the Intersmooth 7460HS scheme, respectively. For all the other raw materials, i.e. 58%, inventories were generated by taking generic and public available datasets and/or through literature, research and partially rough estimations on the production (see table 5). For detailed information regarding how the production of the raw materials has been modelled, contact AkzoNobel Sustainability. The influence of raw materials to the overall results and conclusions of the study are elaborated in the sensitivity analysis.

Some cut-offs were made for certain stages of the life-cycle. The production and waste treatment of the packaging material related to the distribution of the raw materials have not been taken into account. Also the waste treatment of any other waste generated at the manufacturing sites has not been included in this assessment. The reason for this is that a very small amount of waste is generated in the manufacturing, and the treatment of this waste is estimated to contribute with less than 1% to the overall environmental impact.

Also input raw materials and/or formulations that contributed less than 1% to the total mass of the finished BAF paint were left out of consideration. In no case however did the coverage through the other materials drop below 97% of the total.

4.2 Methods/formulas used

Greenhouse gas emissions were accounted according to IPPC AR5

The only processes in the studied system for which allocation is an issue are processes related to the production of some of the raw materials and the waste treatment of the waste items after new building and maintenance at repair and removal.

For the raw materials which have been estimated through literature research, and for the production systems modelled with help of information from suppliers, allocation based on mass has been applied mainly due to the limited amount of information available for these production systems that would be needed in order to allocate in a different way. For the raw materials for which publicly available inventories have been used, the allocations in the underlying LCA studies have not been changed.

The waste treatment facility to which the paint containers from the new building are sent treats many different waste flows in the same processes. All the inputs to these processes and all the emissions from these processes, except carbon dioxide emissions, have been allocated to the different waste flows based on mass. The emission of fossil carbon dioxide has been calculated according to the carbon content of the waste. However, this waste treatment system also produces heat, which is supplied to the local district heating system, and steel. The amount of heat and steel that is produced for a certain waste flow is calculated according to the heat content of the waste and the content of recoverable steel. In this case, allocation has been avoided by applying the system expansion (or avoided impacts) approach, which in this case results in that a credit is given to the coating system, which corresponds to the environmental impacts that would be generated if the heat produced by the waste incinerator and the steel recovered, would be replaced by heat production in a natural gas boiler and production of virgin steel.

The landfill facility to which the paint containers and grit and old paint from the new building are sent produces electricity, which is supplied to the national electricity system. Also in this case, allocation has been avoided by applying the system expansion approach, which in this case results in that a credit is given to the coating system, which corresponds to the environmental impacts that would be generated if the electricity would be produced in the same way as average Saudi Arabian electricity.

5. Results

The basic vessel classes considered in this study were Bulk Carrier, Crude Oil Tanker, Container Ship, Liquid Natural Gas carrier (LNG), Roll-On Roll-Off ferry (Ro-Ro) and Cruise Liner. The results for the different vessel classes showed very similar patterns, and generated the same conclusions. Hence, in order to limit the length of this report only the results for the container ship will be presented here. However, the results for the other vessel classes are readily available on request. All results are presented relative to the functional unit.

As the aim of the study is to identify the environmental consequences of choosing the Intersleek fouling control system instead of the Intersmooth 7460HS system, the results show the difference in environmental impacts when choosing Intersleek 1100SR or Intersleek 700, respectively instead of Intersmooth 7460HS as BAF paint.

The results show that the Intersleek fouling control systems have lower GHG emissions when compared to Intersmooth 7460HS. The impacts related to the fuel use during the in service stage represent almost 100% of the studied systems total GHG emissions and by far outweigh impacts related to production, distribution, and application of the paints.

TABLE 11 - TOTAL GHG IMPACT FOR THE REFERENCE SYSTEM.

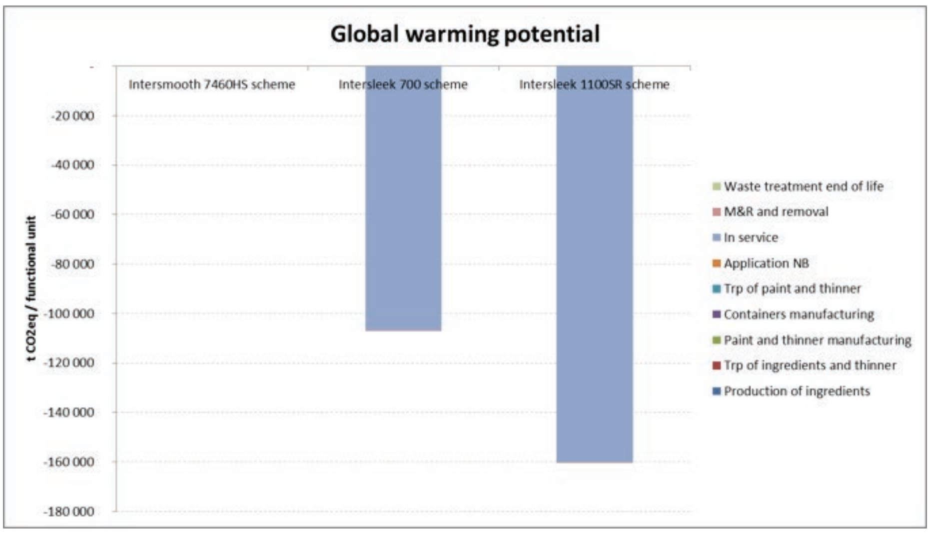
Category	Intersmooth 7460HS	Intersleek 700	Intersleek 1100SR	Unit
Global warming potential	2 664	2 557	2 504	ktonne CO2-equiv.

The following graphs illustrate the differences between the different anti-fouling schemes. “Production of ingredients” hereby describes the total amount of paints produced over the entire life-cycle. “Application NB” as well as “M&R and removal” only cover the energies used and specific emissions directly arising from those activities.

TABLE 12 - AVOIDED GHG EMISSIONS RELATIVE TO THE REFERENCE SYSTEM.

	Intersmooth 7460HS scheme	Intersleek 700 scheme	Intersleek 1100SR scheme	unit
Production of ingredients	-	- 81	- 84	t CO2eq / functional unit
Trp of ingredients and thinner	-	- 12	- 12	t CO2eq / functional unit
Paint and thinner manufacturing	-	- 2	- 2	t CO2eq / functional unit
Containers manufacturing	-	- 3	- 4	t CO2eq / functional unit
Trp of paint and thinner	-	- 3	- 3	t CO2eq / functional unit
Application NB	-	- 33	- 31	t CO2eq / functional unit
In service	-	- 106 550	- 159 819	t CO2eq / functional unit
M&R and removal	-	- 106	- 105	t CO2eq / functional unit
Waste treatment end of life	-	-	-	t CO2eq / functional unit
SUM	-	- 106 790	- 160 060	t CO2eq / functional unit
avoided emissions (rel.)	0%	-4%	-6%	

FIGURE 3 - DIFFERENCE IN GLOBAL WARMING POTENTIAL.



The credit for the avoided emissions belongs to the complete value chain even though the credit is dominated by the “In service” stage.

AkzoNobel International paint claims the most important part of the avoided emissions for itself due to the specific chemical nature and the properties of the Intersleek range products.

6. Key parameters

The impacts related to the fuel use during the in service stage represent almost 100% of the studied systems total green-house gas emissions, and by far outweigh the impacts related to the production, distribution, and application of the paints.

7. Integrating uncertainties and scenarios of future developments

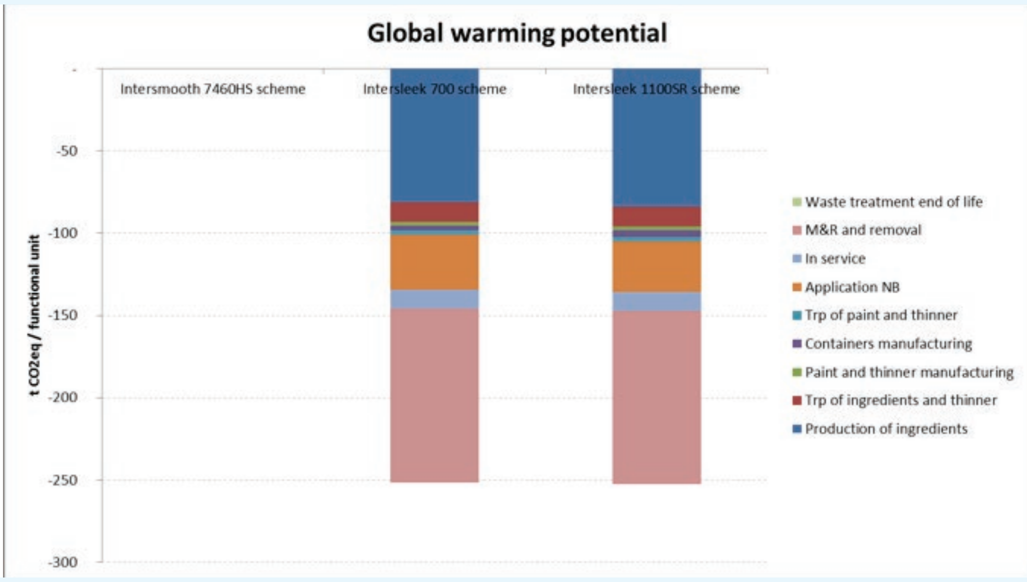
Since the fuel efficiency during the operation of the vessel is dependent on several other factors which the choice of coating system does not influence, the real fuel requirements will vary from vessel to vessel and between different service periods. Furthermore, in a future scenario in which vessels can operate on sustainable fuels, less weight will be put on fuel requirements, and more focus will be put on the materials of the vessels.

In order to take these aspects into account and to highlight the GHG emissions of the production, distribution, application, maintenance, and removal of the paints, the fuel requirements and use of lubricant oil during in service are now set to be independent of the choice of coating system. All activities related to the fuel and lubricant oil can therefore be excluded from the comparison. To simplify interpretation, the results for the Global warming potential impacts are now presented as the impacts associated with the use of each coating system. The differences between the impacts represent GHG emissions-related consequences of a change between fouling control system.

TABLE 13 - AVOIDED GHG EMISSIONS RELATIVE TO THE REFERENCE SYSTEM (EXCL. FUEL CONSUMPTION)

	Intersmooth 7460HS scheme	Intersleek 700 scheme	Intersleek 1100SR scheme	unit
Production of ingredients	-	- 81	- 84	t CO2eq / functional unit
Trp of ingredients and thinner	-	- 12	- 12	t CO2eq / functional unit
Paint and thinner manufacturing	-	- 2	- 2	t CO2eq / functional unit
Containers manufacturing	-	- 3	- 4	t CO2eq / functional unit
Trp of paint and thinner	-	- 3	- 3	t CO2eq / functional unit
Application NB	-	- 33	- 31	t CO2eq / functional unit
In service	-	- 12	- 12	t CO2eq / functional unit
M&R and removal	-	- 106	- 105	t CO2eq / functional unit
SUM	-	- 252	- 253	t CO2eq / functional unit
avoided emissions (rel.)	0%	-58%	-58%	

FIGURE 4 - DIFFERENCE IN GLOBAL WARMING POTENTIAL (EXCL. FUEL CONSUMPTION)



From the diagrams it is evident that the Intersleek 700 and 1100SR coating systems perform significantly better than the Intersmooth 7460HS system in terms of global warming potential. The main reason for this is that less volume of coating is needed since the Intersleek finish coatings are not self-polishing coatings and since they have shown to have higher resistance to damage (less paint is emitted due to mechanical forces.

Other outstanding results are:

- The alternative's performance in GWP is highly correlated to the volumes of paint. This is a consequence of the following aspects of the coating systems:
  - There is a relatively small difference between the paints on a volume by volume basis with regard to solvent content and impacts in these impact categories.
  - The raw material production has the highest contribution to the GWP, however the emissions of solvents (VOC) at application of the paint during new building and maintenance and repair also has a high contribution.

Hence, it is evident that the major opportunity for environmental impact mitigation is to produce biocidal antifouling control systems which:

- Further enhance the fuel efficiency during vessel operation
- Require lower amounts of paint
- Are based on lower amounts of solvents
- Are produced from raw materials which are based on renewable or non-scarce resources

However there are other aspects which also are important in the longer term, such as working with the complete supply chain to facilitate sustainable material management. For example, renewable solvents can be treated before being emitted, and cans, tins and non-used paint can be managed via a take back scheme.

The studied system is comprehensive and modelled at a high level of detail to ensure that no major impacts would be overseen, however a cut-off was made for the treatment of raw material packaging waste and other waste from the manufacturing of the paints. Considering that the impact of this waste normally has a small impact in relation to the production of the raw materials and paint, this cut-off of waste treatment in manufacturing is not considered to influence the outcome of this study. This is further supported by the fact that there are no major differences in the amount, category and treatment of the raw material packaging waste between the three systems, hence also the relative environmental impact from the raw material packaging waste of the three systems is likely to be aligned with the paint volumes required.

Even at no reduction in fuel requirements (which is the base case assumption), the Intersleek systems have significantly lower GHG emissions. This is mainly because less paint is needed and since the reduction in environmental impact is valued to motivate the higher paint costs associated with the Intersleek systems by the applied weighting methodology. The Intersleek systems also reduce dependency on scarce resources, especially copper, and emissions of VOC, which are important aspects when looking at the overall environmental impact of paint.

Finally, a transition to raw materials based on renewable and less scarce resources (especially copper) and to paints with lower solvent content will be required in order to safeguard from future sustainability pressures.

8. Qualitative assessment attribution

According to the functionality approach as presented in table 3 in the avoided emissions guidelines the contribution of the Intersleek product to the value chain avoided emissions is "fundamental"

References

[1] Candries, M., Atlar, M. (2005), "Experimental Investigation of the Turbulent Boundary Layer of Surfaces Coated with Marine Antifoulings", Journal of Fluids Engineering, Vol 27

[2] Candries, M., Atlar, M. (2003), "On the Drag and Roughness Characteristics of Antifoulings", Journal of Maritime Engineering, Vol 27

[3] Marine Engine, IMO Tier I, Programme 2009

Case 11 The Green Sense® Concrete solution – optimizing concrete mixtures by reducing cement content

BASF

COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned by BASF Construction Solutions GmbH, performed by Anahí Grosse-Sommer of BASF SE and David Green of BASF Corporation and reviewed by Quantis

1. Purpose of the study

This comparative life cycle assessment was conducted to quantify the environmental benefits associated with lowering the cement content of concrete mixtures. Specifically, this study conducted according to ISO 14040 and ISO 14044 examines the avoided greenhouse gas (GHG) emissions of concrete mixtures based on the optimization of the concrete mixture design through the use of supplementary cementitious materials and the appropriate chemical admixtures to meet or exceed design and construction specifications. The effect of such a substitution on environmental impact categories besides GHG emissions is briefly addressed as well.

This analysis serves as a case study according to the requirements listed in "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 WBCSD chemical sector group in 2013 and updated in 2016. It is a Category 3 study in which average concrete mixtures are compared with mixtures requiring lower cement content and containing unique admixtures to meet or exceed the original design specifications.

2. Solutions to compare

2.1 Description of the solutions to be compared

Two concrete mixtures were compared in this study: a conventional standard concrete mixture and an optimized concrete mixture. The optimized mixtures, known as Green Sense® Concrete, are designed for specific building applications in which proprietary admixture solutions are selected to maintain or exceed the original concrete properties while reducing the cement content. Cement is associated with a large carbon footprint due to the calcination process required during its manufacture. Certain cement replacement materials may require unique admixtures to attain the appropriate performance characteristics of the concrete design. The appropriate admixture selection and application supports the cement reduction while keeping concrete properties, both in the fresh and hardened state, at an optimum level. Green Sense® Concrete mixes are developed by BASF for a specific customer application to achieve high technical performance at reduced environmental impact and thus vary from one construction project to another.

Concrete is generally composed of binders, aggregates, admixtures and water. The binder, typically cement, is activated by water and serves to bind together and solidify the aggregates such as sand or gravel. The input materials for the concrete mixtures compared in this study are shown in Table 1. Due to confidentiality considerations, the average of 250 actual studies is reported here rather than one specific concrete mix. Thus, the conventional concrete mixture composition is representative for typical North American construction and is based on the average of 250 concrete mixtures; the Green Sense Concrete composition in the table is similarly the average of 250 actual Green Sense Concrete mixtures that were developed by BASF for customers' residential, institutional and commercial construction projects in the US in the time period 2012-2016.

TABLE 1 - INPUT MATERIALS OF THE CONCRETE MIXTURES

Material		conventional concrete mix	Green Sense® Concrete mix
cement	kg/m³	299	196
slag	kg/m³	8	133
sand	kg/m³	832	819
gravel	kg/m³	1030	1001
admixtures	ml/100kg	707	798
water	l/m³	160	156

While the conventional concrete mixture also contains generic admixtures, the Green Sense Concrete mixture is evaluated in the laboratory to best address specific construction application needs. Admixtures included in the concrete mixtures include water reducers, air entrainers and workability-retaining admixtures.

The properties of the Green Sense® Concrete with reduced cement content are comparable or improved when compared to the conventional mixture. To simplify the comparison, it was assumed that the properties were the same. Relevant attributes include, for example, workability of the wet mixture and strength of the hardened concrete.

2.2 Definition of the boundaries of the market and the application

Concrete is the most widely used man-made material in the world. On average nearly three metric tonnes of concrete are used per person every year (2). In the USA, annual production of concrete is over 500 million metric tonnes (3). Green Sense Concrete® can replace substantial amounts of conventional concrete, its use effectively limited by the availability of secondary cementitious materials (SCM) such as slag or fly ash. These SCM are produced in the range of hundreds of millions of tons annually. BASF offers the solutions on a global basis and more than 100 million cubic meters of concrete with high SCM content have been placed so far.

3. Functional unit and reference flow

3.1 Functional unit

The functional unit of this study is the production of 1 m^3 concrete for general construction projects for the US market in the time period 2012-2016. The density of these concrete mixtures is about 2300 kg/m^3. The functional and technical properties of the concrete mixtures are comparable, so the use and end-of-life phase are assumed to be identical and are not included in the system boundaries.

3.2 Reference flow

The reference flow is 1 m^3 of concrete. The admixture amount varies by alternative according the input materials shown in Table 1.

3.3 Quality requirements

Concrete must fulfill quality requirements both during application of the building materials as well as in the use of the completed building structure. In the wet state, concrete needs to be easily workable, easy to pump, place and set. In the hardened state, concrete has to be durable and require minimal maintenance. Both concrete mixtures in this study fulfill these requirements. Advantages of the Green Sense® Concrete mix – such as good workability in extreme environments, pumpability to hundreds of meters in height, and decreased hardening times – have not been included in this assessment since the effects of these advantages on environmental impacts are difficult to quantify.

3.4 Service life of the solution

Concrete structures have varying life spans that vary with use, climate conditions and more. The concrete mixtures in this study are assumed to have a service life of 50 years. However, in this study the use of the concrete structures is not included; therefore, the service life has no relevance for the assessment.

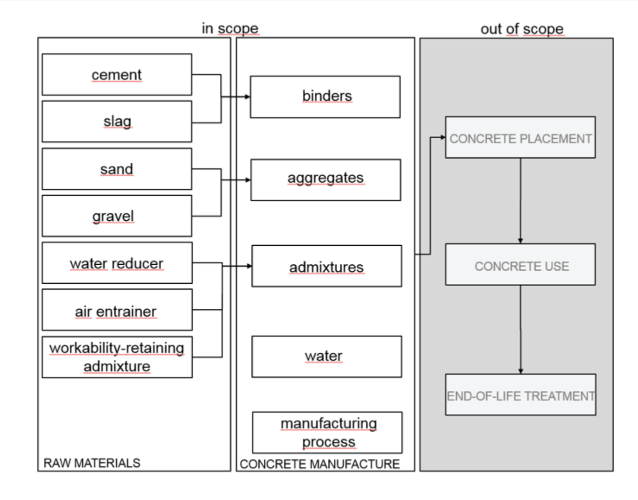
3.5 Time and geographic reference of the study

The study covers construction projects in the US market in the time period 2012-2016.

4. Boundary setting

The system boundaries of the average concrete mixture are shown in Figure 1. The study includes the production of concrete components including binders, aggregates, admixtures, and water. Mixing, placement, use and end-of-life of the concrete mixtures are identical and not included in this assessment. Compared to the impacts of the concrete raw materials on GHG emissions the contribution of these life cycle steps are small.

FIGURE 1 - SYSTEM BOUNDARIES



For the raw materials used in concrete manufacture, transportation to the manufacturing site has been taken into account. These transportation distances are shown in Table 2.

TABLE 2 - RAW MATERIAL TRANSPORTATION DISTANCES AND MODE

Material	transport distance (km)	mode (km)
cement	200	truck
slag	1000	barge
sand	100	truck
gravel	100	barge
admixtures	100	truck

5. Calculation methodology and data

5.1 Methods and formulas used

This study is a cradle-to-gate assessment of the following environmental impact categories:

- climate change [kg CO_2-eq]
- photochemical ozone formation [kg NMVOC-eq]
- ozone depletion [kg CFC11-eq]
- acidification [mol H+-eq]
- eutrophication marine [kg N-eq]
- eutrophication freshwater [kg P-eq]
- resource depletion [kg Sb-eq]
- human toxicity [toxicity points]

With the exception of the global warming potential and the toxicity potential the impact assessment methodology follows the EU PEF Guidance (4). EU PEF assessment methodology for climate change is based on IPCC 2007 100-year values. For this comparative study the climate change characterization factors used are according to AR5 (5) as implemented in the GaBi Software (thinkstep AG, compilation 7.2.2.28). The human toxicity potential follows BASF methodology (6, 7) and has been implemented in the GaBi Software by thinkstep AG as well.

5.2 Allocation

No allocation was needed for the input data. Some of the life cycle inventory (LCI) data of the background processes may include allocation. The assumptions underlying any allocation in generic product pre-chains are documented in the corresponding database.

5.3 Data, data sources and data quality

The foreground data, i.e. the concrete mixture compositions, are based on 250 comparative life cycle assessment studies that BASF has completed in recent years, comparing average concrete mixtures with Green Sense® Concrete mixtures.

These assessments cover actual Green Sense® Concrete mixture compositions based on laboratory optimization.

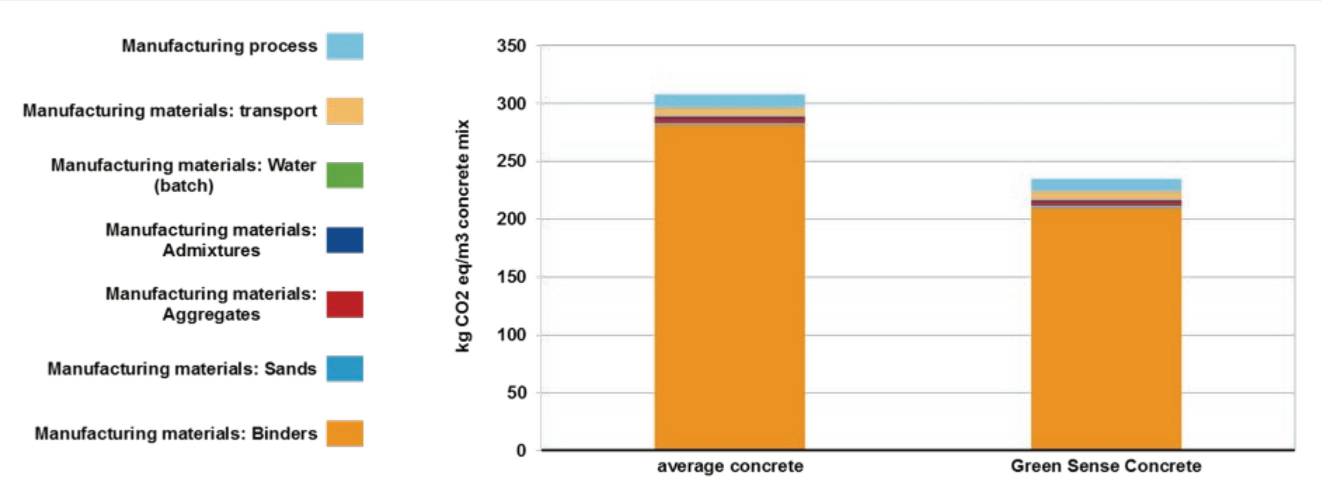
LCI data comes from the GaBi database (thinkstep AG, database version 6.115). These are average LCI and quality is assumed to be appropriate for the purpose of the study. Admixtures for the Green Sense® Concrete mixture are based on actual BASF admixture production processes and the primary data is of high quality.

6. Results

6.1 Avoided GHG Emissions

The cradle-to-gate GHG emissions associated with the production of the two concrete mixtures are shown in Figure 2. The binder components, i.e. the cement and slag, dominate the product carbon footprint. The contributions of the other materials are essentially negligible. Transportation of raw materials and the manufacturing process (e.g. energy) contribute about 10% to the cradle-to-gate GHG emissions associated with each concrete mixture.

FIGURE 2 - GREENHOUSE GAS EMISSIONS OF CONCRETE MIX ALTERNATIVES



The avoided emissions along the value chain are thus 73 kg CO_2-eq/m³ concrete (Table 3).

TABLE 3 - AVOIDED GREENHOUSE GAS EMISSIONS OF CONCRETE MIX ALTERNATIVES

Emissions per step (kg CO_2-eq/m³ concrete)	Average concrete mix	Green Sense® Concrete mix
Raw material: binders	283	211
Raw material: sands	2	2
Raw material: aggregates (gravel)	4	4
raw materials: admixtures	1	1
Raw materials: water	0.04	0.03
Transportation	8	7
Manufacturing process	12	12
Total	309	236
Avoided emission	73	

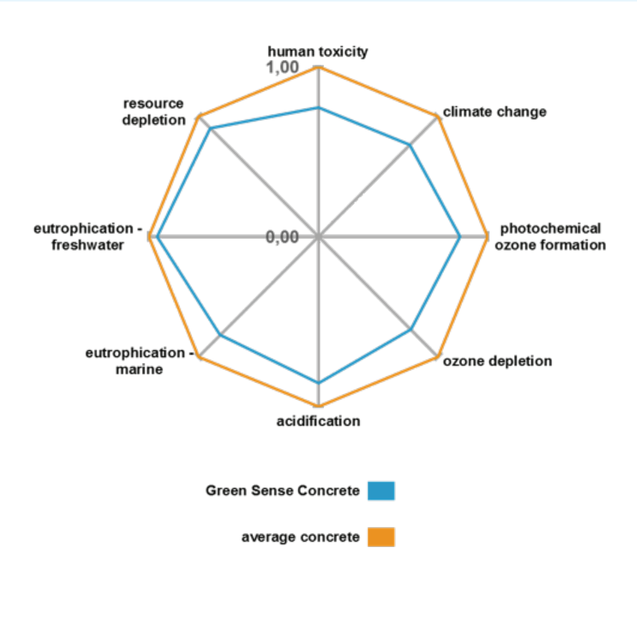
6.2 Scenario analysis

No scenarios were calculated.

6.3 Other environmental impact category results

Figure 3 shows the relative performance of the two concrete mixtures in all impact categories assessed. The alternative with the highest environmental impact is normalized to a value of one, whereas the concrete mixture with the lower burden thus lies somewhere between zero and one. The environmental impact in all categories – photochemical ozone formation, ozone depletion, acidification, eutrophication (marine), eutrophication (freshwater), resource depletion, human toxicity as well as climate change – are lower for the Green Sense® Concrete mixture. Therefore, there is no trade-off associated with the avoided GHG emissions. Detailed diagrams of the results for all these impact categories are shown in the appendix.

FIGURE 3 - OVERVIEW OF ALL ENVIRONMENTAL IMPACTS ASSESSED



7. Significance of contribution

Certain BASF admixtures allow for the partial substitution of the concrete component cement in Green Sense® Concrete mixtures with other materials having a lower carbon footprint. The admixtures thus support the use of supplementary cementitious materials to enable reductions of greenhouse gas emissions, so both producer and user of the admixture contribute to the avoided emissions. In addition, producers of alternative cementitious binders such as the slag provide the material to replace cement content. Therefore, various players along the value chain contribute to GHG emission reduction.

8. Review of results

A critical review of the Green Sense® Concrete calculation tool was completed by NSF International in 2016. The tool was validated according to NSF Protocol P352 Validation and Verification of Eco-Efficiency Analyses (8).

9. Study limitations and future recommendations

This study is based on approximately 500 concrete mixture compositions as used in specific construction projects in the US. The results may not be applicable to specific construction projects in the US and the concrete mixture compositions may differ from other regions.

For the study it was assumed that both average concrete mixtures and Green Sense® Concrete mixtures show similar maintenance requirements during building use. Lab tests indicate that Green Sense® Concrete may have advantages during use due to higher durability and reduced maintenance costs. Taking into account these differences during building life cycles would result in additional avoided greenhouse gas emissions.

10. Conclusions

This study compares average concrete mixtures with optimized concrete mixtures, known as Green Sense® Concrete. Green Sense® Concrete is a BASF concrete optimization solution that incorporates advanced admixture solutions that allow for partial substitution of cement with other cementitious materials having lower greenhouse gas emissions.

The average concrete mixture product in this study is associated with GHG emissions of 309 kg CO_2-eq/m^3, while the Green Sense® Concrete mixture in this study results in 236 kg CO_2-eq/m^3. Avoided emissions of 73 kg CO_2-eq/m^3 concrete were thus possible with the Green Sense® Concrete mixture relative to the average concrete mixture, including raw materials and manufacturing process needed to produce wet concrete. The placement, use and end-of-life stages were not included in the study because they were assumed to be identical. Cement is the single largest contributor to the cradle-to-gate greenhouse gas emissions. Transport of raw materials and manufacturing process needed for concrete mixing have a minor effect, while other materials have a negligible contribution to the carbon footprint in this study.

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12. Appendix

The following figures show the results of the other environmental impact categories.

FIGURE 4 - PHOTOCHEMICAL OZONE FORMATION

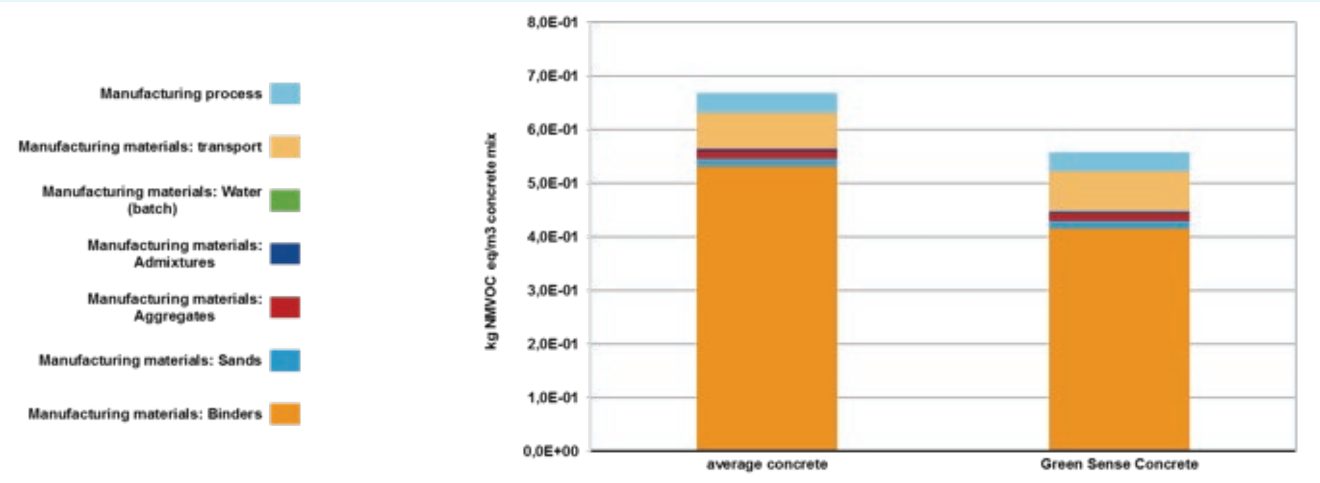


FIGURE 5 - OZONE DEPLETION

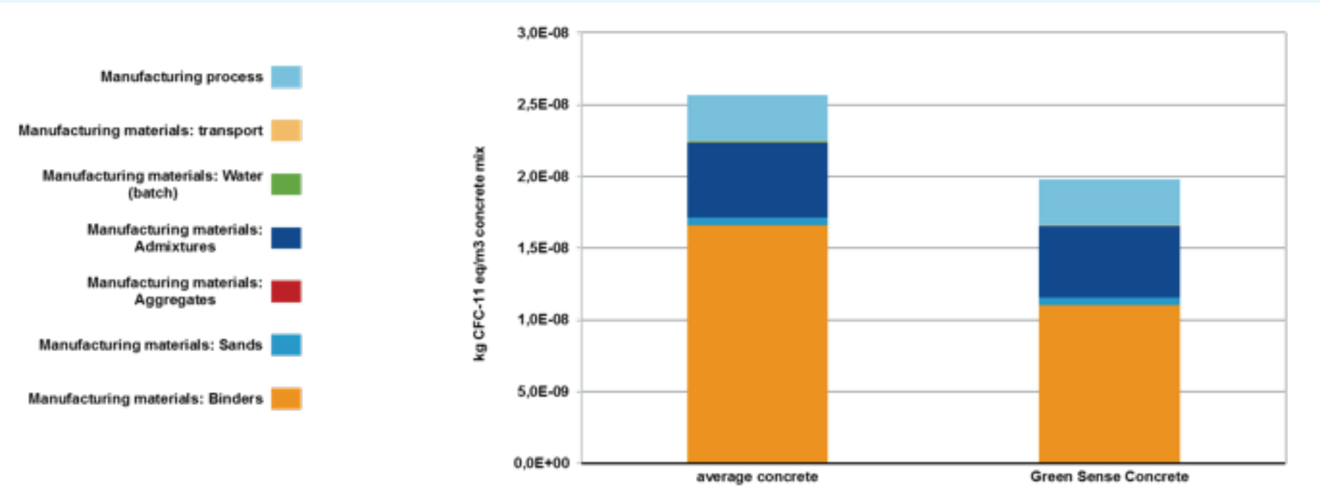


FIGURE 6 - ACIDIFICATION

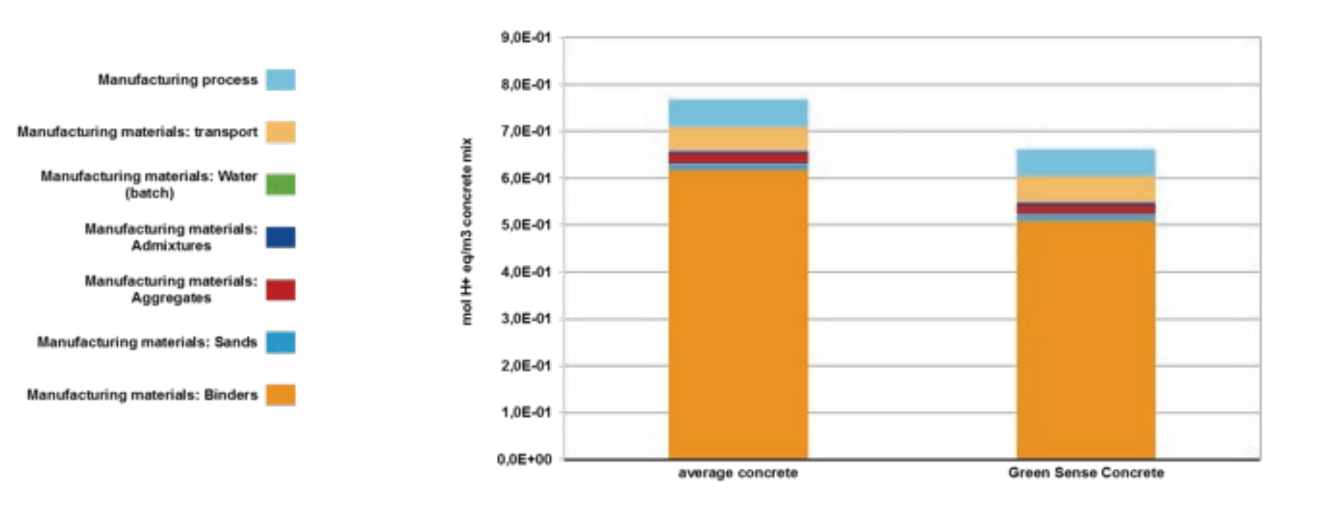


FIGURE 7 - EUTROPHICATION (MARINE)

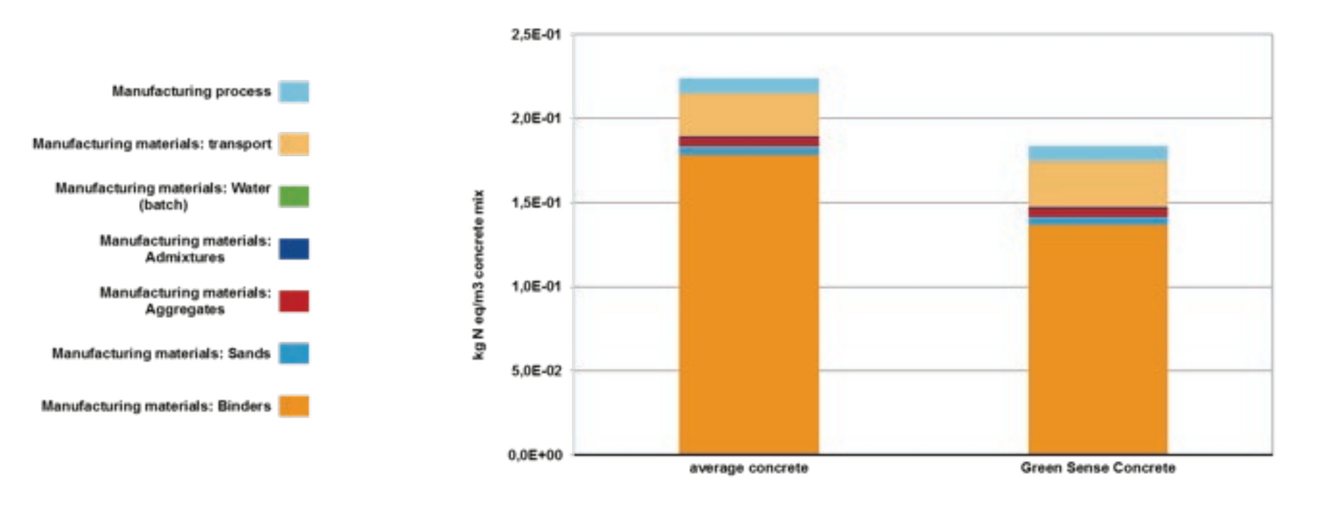


FIGURE 8 - EUTROPHICATION (FRESHWATER)

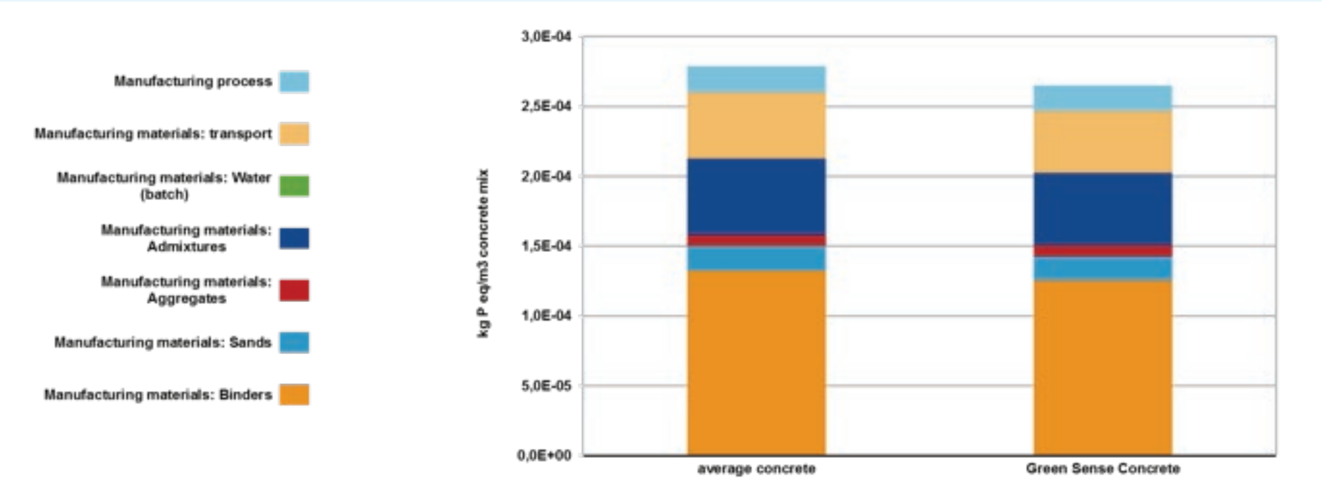


FIGURE 9 - RESOURCE DEPLETION

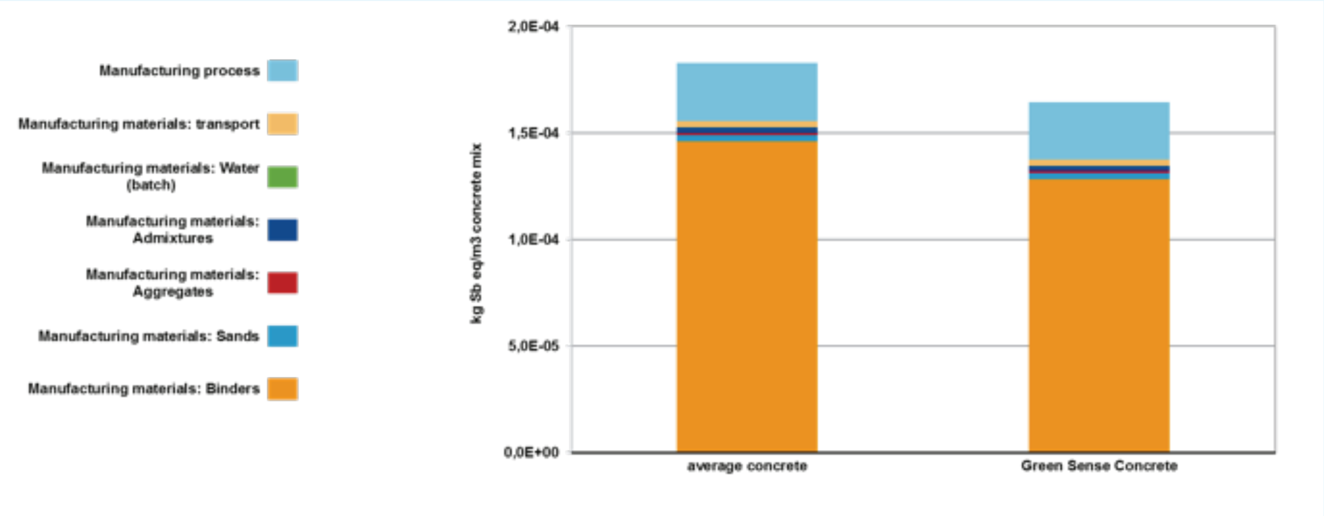
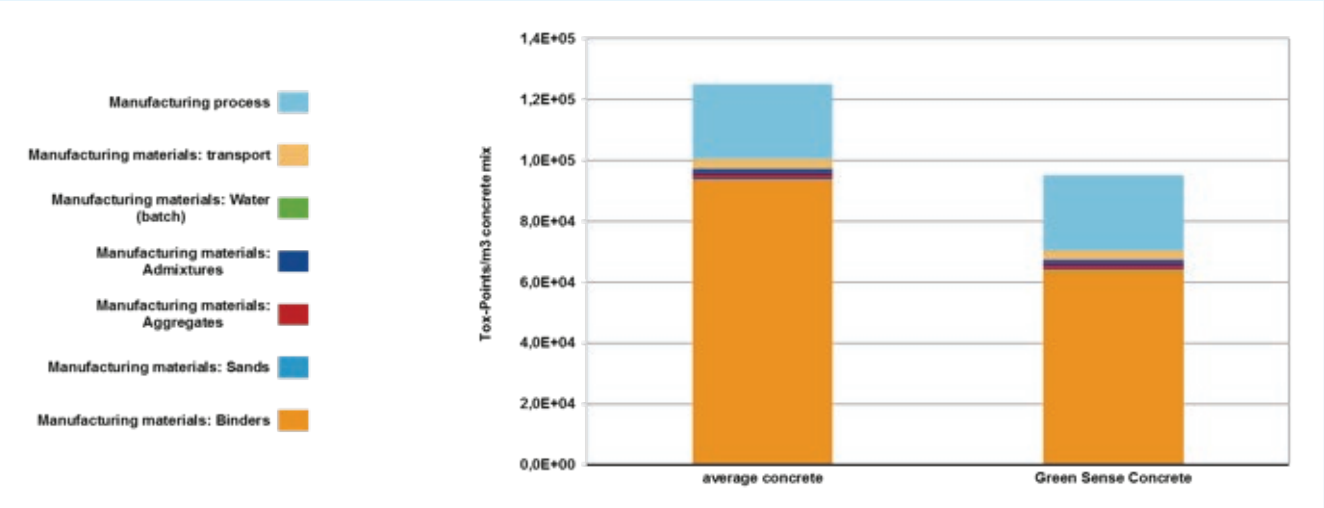


FIGURE 10 - HUMAN TOXICITY



Case 12 Polypropylene (PP) containers for water-based paints

Braskem

COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned by Braskem, executed by ACV Brasil and reviewed by Quantis.

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 the manufacturing of rigid containers for water-based paints, 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

PP containers and the lids are injected, both using virgin only resin. Tinplate containers are welded and a layer of varnish is applied. The filling process of the packages is assumed as being equal for both alternative solutions. The use (and eventual re-use) of the packages is also considered as being equivalent. The alternative solutions considered in this study fulfil the same function and meet the minimum requirements accepted by the market.

2.2. Level in the Value Chain

The study focuses on the use of PP resin for 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

994 million liters of water-based paints were sold in Brazil in 2016 (Abrafati, 2017). The market for water-based paint containers in Brazil is dominated by the tinplate alternative, with 92%, followed by the analyzed fossil PP alternative, with 8% [1].

3. Functional unit and reference flow

3.1 Functional unit

The function has been defined as "to pack water-based paint for storage and transportation". The functional unit has been set as to pack for storage and transportation 1,800 L of water-based paint.

Both alternatives considered in the study fulfil the same function. The market considers that both alternatives provide the same shelf-life for the paints, therefore the technical performance of the systems are equivalent.
All data are representative of the Brazilian market in year 2016.

3.2. Reference flow

The table below shows the reference flows for each alternative.

	PP	Tinplate
Mass of each 18 L container	740 g	980 g
Reference flow (100 containers)	74 kg	98 kg

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;
- Decoration of the containers
- Distribution;
- End-of-life of the containers.

Both containers are filled in the same way. Therefore the 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 and technical performance. It is also assumed that they have no differentiation during the use phase.

1 There are two alternatives in the market for water-based paints: 3.6 L gallons and 18 L containers. However, the smallest avoided emission is found for the 18 L alternative. Therefore, for simplification, only this alternative will be considered.

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

FIGURE 1 - PRODUCT SYSTEM FOR TINPLATE CONTAINERS

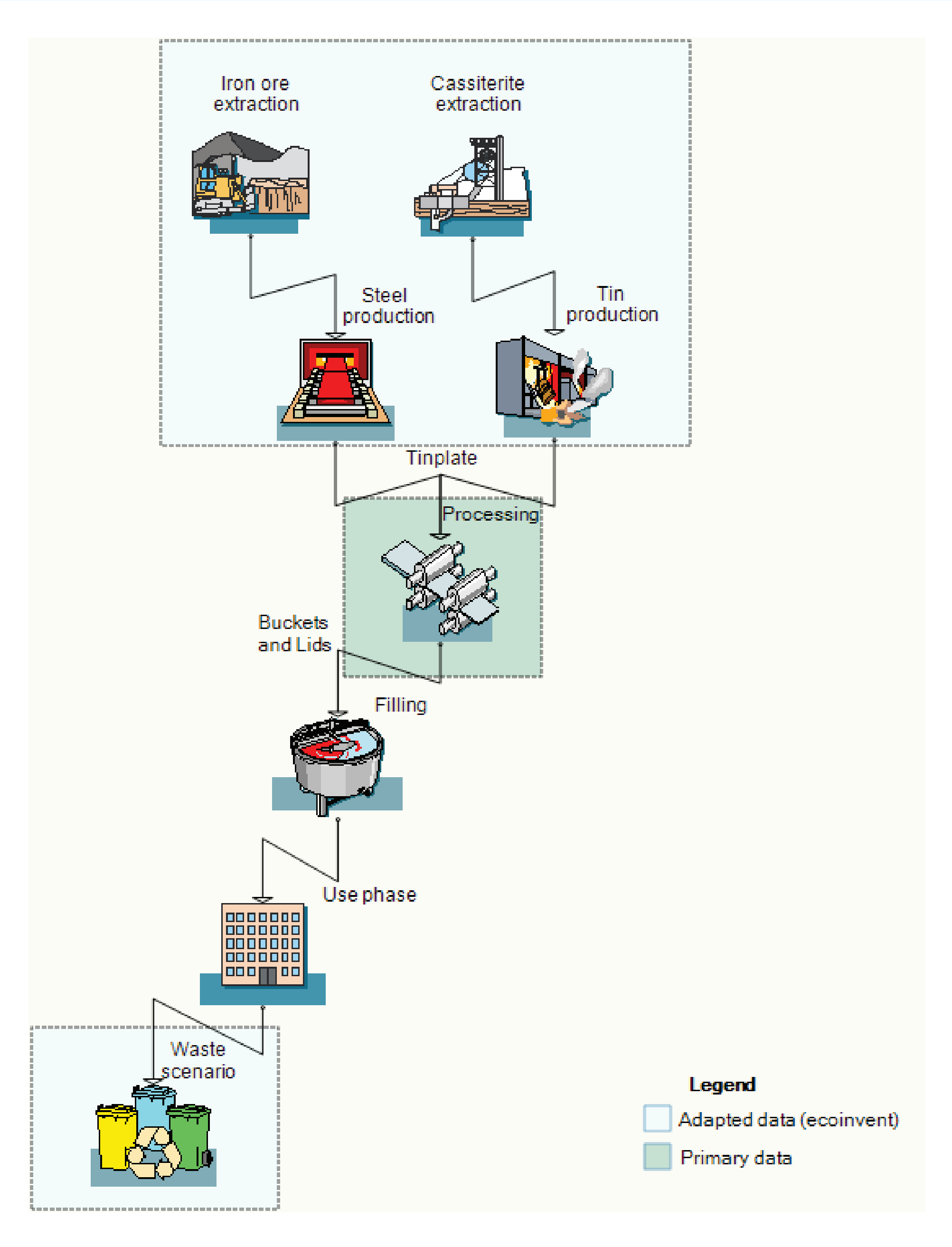
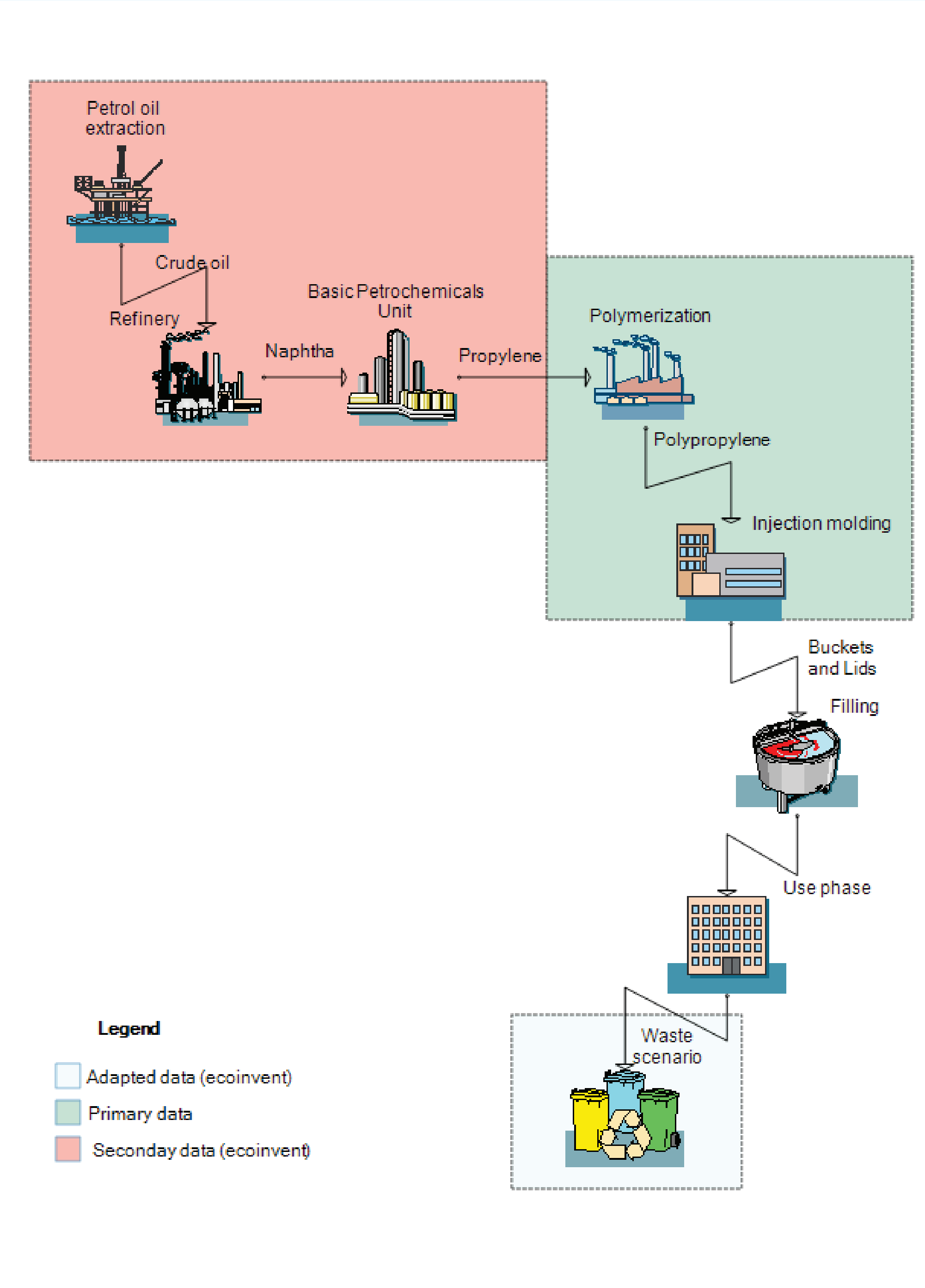


FIGURE 2 - PRODUCT SYSTEM FOR POLYPROPYLENE (PP) CONTAINERS



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 8.0.5. The impact method used was IPCC 2007 GWP, with characterization factors for a timeframe of 100 years [IPCC 2007]. The 2007 version of the IPCC report was used since the most current data (IPCC 2013) had not been implemented in the LCA software when the full LCA was performed.

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 50/50 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.

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 v3.

The full LCA report (in Portuguese) is provided for further understanding of the trade-offs involved and therefore, the original data are presented here for consistency.
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

Component	Material or process	Data Source	Reference Year
PP Container	Polypropylene, at PP5 plant of Braskem/BR U mix	Braskem/ACV Brasil	2011-2012
	Injection moulding/RER U	Ecoinvent v3 based on [Habersatter et al 1998] and [Boustead 1997]	1997-1998
Tin Plate Container	Steel, converter, low-alloyed, at plant/BR U	Ecoinvent v3 based on basic oxygen furnaces in Europe and [IPCC 2001]	2001
	Hot rolling, steel/BR U	Ecoinvent v3 based on [IPCC 2001]	2001
	Tin plating, pieces/BR U	Ecoinvent v3 based on data from an established galvanizing company in central Europe	2001-2005
	Sheet rolling, steel/RER U	Ecoinvent v3 based on [IPCC 2001]	2001
	Steel product manufacturing, average metal working/RER U	Ecoinvent v3 based on eight environmental reports of companies in the engineering business	2002-2005

6. Results

6.1 Avoided emissions

The life cycle of each alternative has been divided in:

- Raw materials extraction and processing;
- Container manufacturing;
- Container decoration;
- Distribution;
- End-of-Life

No emissions were assigned for the use phase.
The detailed results are shown in Table 2.

TABLE 2 – THE RESULTS OF THE CASE STUDY

Life cycle stage	PP containers ($kgCO_2e$/Functional unit)	Tinplate containers ($kgCO_2e$/Functional unit)
Raw material	135	370
Manufacturing/ Processing	114	
Decoration	36	14
Transport	9	27
End of life/Disposal	6	-41
Total	300	370
Avoided Emissions	**70 $kgCO_2e$/FU**	

"Raw material" life cycle stage refers to oil extraction, oil refining, naphtha cracking, production 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 used for the production of pig iron and steel, and to the emissions from these processes. As for the PP resin, this stage is dominated by the oil extraction and the production of PP.

The end of life of the tinplate containers 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. However, this alternative shows lower emissions regarding its reduced weight comparing to the tinplate containers.

Considering 2016 market data, 994 million liters of water-based paints were sold in Brazil, 914.5 million litters in tinplate containers. If all that market share were to be replaced by PP containers it would mean a potential avoided emission of 35'756 tCO_2e.

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. The contribution of PP resin to the final Avoided Emissions can be qualified as "extensive", 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. However, the calculated avoided emissions are to be attributed to the complete value chain, and not only to the chemical company.

8. Review of results

Both the avoided emissions study and the full LCA that supports it have been reviewed by KPMG and their considerations were incorporated in the original report. 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, such as Ecoinvent v3.

Data coming from the Ecoinvent database, despite 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 water-based paints in the Brazilian market. The reduction in GHG emissions by the use of rigid PP containers instead of tinplate containers is estimated at about 20%.

Furthermore, an increase in the recycling rates is beneficial to all the packaging systems, therefore it is recommended to develop solutions to reduce 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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12. Appendices

None

Case 13 Alternative product distribution logistics

Eastman Chemical Company

COMMISSIONER AND PERFORMER OF THE STUDY

The study was performed by Eastman and reviewed by Quantis.

1. Purpose of the study

The goal of this study is to characterize the avoided emissions associated with an innovative mode of chemical product distribution logistics between Eastman and other chemical company partners, which is termed "Alternate Methods of Supply" (AMS). This study was initiated and performed by Eastman Chemical Company to better understand the life cycle impacts of the Eastman supply chain. The ICCA-WBCSD "Addressing the Avoided Emissions Challenge" guidelines version 2 were used to prepare the study.

AMS can be used when two chemical companies produce a practically identical and mutually interchangeable chemical product in two separate geographic regions. If both companies are willing to engage in AMS then a specific quantity of chemical product can be swapped in order to reduce the amount of inter-continental transportation required to distribute that product to customers. Such a swap is done under a bilateral agreement and it represents an alternative method of shipping as compared with standard shipping methods where each company distributes its own products globally.

The names of Eastman's AMS partners and the identity of the chemical products being distributed are confidential.

2. Solutions to compare to

2.1. Description of the solution to compare to

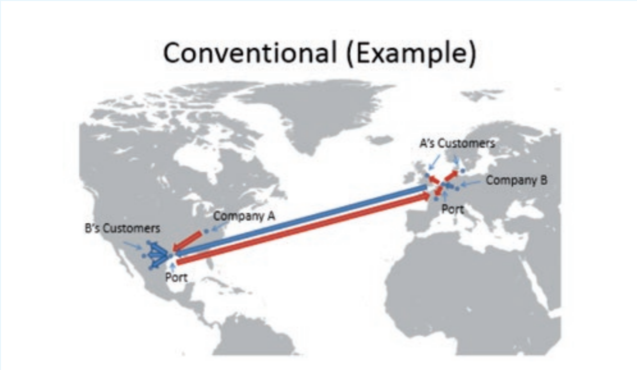
AMS is compared against the baseline conventional product distribution in which each company transports its own products to its own distribution centers in other continents. In either case, Eastman and its partner chemical companies produce a certain amount of fungible chemical products and distribute the products to distribution centers & customers. AMS is purely an alternative method of logistics that can be used if mutually agreeable between two chemical companies.

2.2. Definition of the boundaries of the market and application

The following figures graphically represent the systems being compared in this study. In general, the resulting savings correspond to the final figure, because only the difference between scenarios can be known without knowledge of the partner company's business. The true difference in the two scenarios is the maritime shipping leg plus any difference in overland shipping.

In Figure 1 below, the conventional system is shown as the solution to compare to. In this scenario, each company fulfills orders to its customers directly no matter where they are located as though it is the only actor in the world.

FIGURE 1 - TRANSPORT OF GOODS UNDER THE BUSINESS AS USUAL SCENARIO WITHOUT UTILIZING BILATERAL AGREEMENTS: THE SOLUTION TO COMPARE TO.



In contrast, Figure 2 shows the solution of the reporting company. Each company is aware of the other's production and when customer demand could be satisfied with a simplified, shorter supply route, the chemical ownership is exchanged between the two companies. The net effect is shown in Figure 3.

FIGURE 2 - TRANSPORT OF GOODS UNDER THE TERMS OF A BILATERAL AGREEMENT BETWEEN COMPANY A AND COMPANY B.

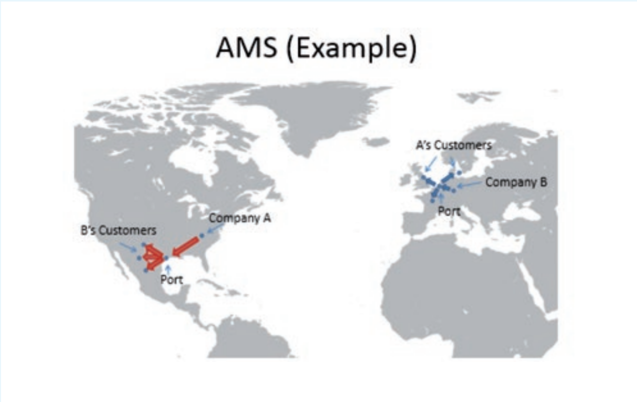
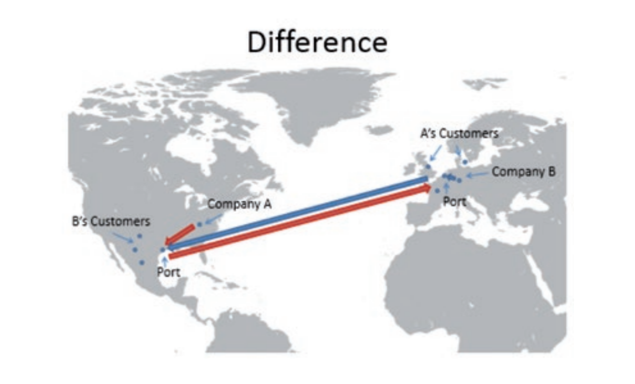


FIGURE 3 - THE DIFFERENCE BETWEEN BILATERAL AGREEMENTS AND CONVENTIONAL SHIPPING. THE TRANSOCEANIC TRIP IS UNNECESSARY UNDER A BILATERAL AGREEMENT. SOME DIFFERENCES IN LOCAL SHIPPING ARE ALSO OBSERVED.



AMS bilateral agreements are typically two sided. Note that these agreements are not necessarily symmetrical and sometimes there is a time delay that doesn't show up on the agreement right away. In theory, it would be a 1:1 swap, but any number of factors could influence the actual amount involved. Eastman calls the receiving and sending of the chemical "purchasing" and "sales" respectively. In a purchasing agreement, Eastman purchases the chemical from a local manufacturer to sell to our overseas customers in that region thus eliminating costly and resource intensive shipping steps. For example, if Eastman has a purchasing agreement with Company B in Europe, Eastman buys from Company B and sells to its customers in Europe from the European facility rather than having to ship from US locations.

It is crucial to understand that sales and purchasing agreements frequently refer to the same material. Thus to avoid double counting, this study calculates ONLY savings from the "sales" part of the agreement. The study compares only the differences in shipping between the conventional shipping solution and that which involves AMS bilateral agreements. Thus the study uses the simplified avoided emission calculation methodology.

3. Functional unit and reference flow

3.1. Description of the function and the functional unit

The functional unit for this study is the delivery of interchangeable material from a manufacturing site to its intended distribution location for an entire year under an AMS bilateral agreement.

3.2. Reference flow

The study is based on a reference flow which corresponds to the total amount of product shipped in 2015 via the bilateral agreements which were included in the study.

3.3. Quality requirements

The material must be functionally the same whether it comes from Eastman's facility or that of another company. Delivery of material can be accomplished via either conventional shipping or AMS. Having the same functionality, technical qualities and benefits from use and end-of-life ensures exchangeability between solutions.

3.4. Service life of the solution

The "service life" of the solution is simply the duration of the transportation of the chemical products.

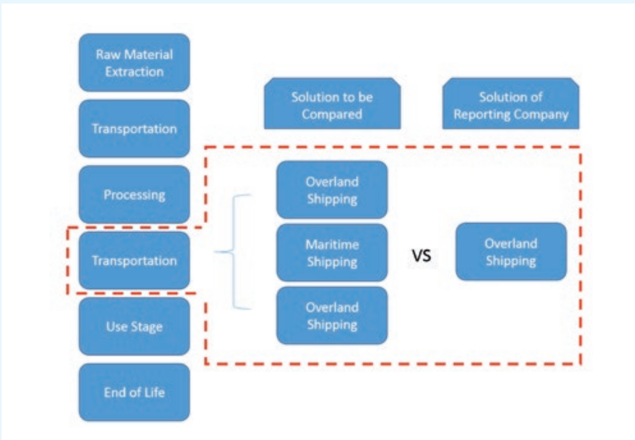
3.5. Time and geographic reference

The temporal scope covers all AMS bilateral agreements for 2015. This temporal scope provides recent data, and the best description of practices. The data represents all bilateral agreements for a representative year, 2015. The supply chain for these products spans the globe and so the geographic reference is the entire world.

4. Boundary setting

The scope of this study is gate-to-gate including only shipment of chemical products. Tradeoffs exist between different overland shipping scenarios. It is not necessarily more efficient to ship overland to customers when maritime shipping is more efficient per tonne-kilometer. As will be discussed in section 7, the difference between scenarios was reduced to the maritime shipping due to lack of knowledge of the location of customers in what would be the solution to compare to.

FIGURE 4 - BOUNDARY FOR THE STUDY - THE RED DOTTED LINE DENOTES THE LEVEL IN THE VALUE CHAIN WHICH IS UNDER CONSIDERATION IN THIS STUDY



5. Calculation methodology and data

5.1. Methods and formulas used

The simplified assessment has been used since the same chemical is being produced regardless of transportation scenarios. The omitted cradle-to-gate global warming potential (GWP) results represent the majority of the emissions for the products being manufactured. The confidential identity of the chemicals does not impact the study since their production is within the omitted portion of the life cycle.

Quantities of chemicals shipped via alternative methods of supply are known and recorded. The traditional supply routes and methods are also known, so it is possible to compare a conventional route to the destination distribution center with an alternative route to a domestic distribution center.

Transportation models are used to find the incremental carbon intensity of shipping per tonne-kilometer. All transportation models are published industry averages for their ship/truck type in GaBi (see section 5.3 below). It is assumed that the ships' percentage load does not depend on the chemicals being shipped and also that there is no wait time in a port.

5.2. Allocation

Most of the background datasets do use some sort of allocation and the default thinkstep allocation for impacts of fuels etc is used and not altered for this study. For transoceanic and overland shipping, the amounts are based on mass, not volume. Shipping of liquids or bulk packaged goods could be measured in m^3-km instead of t-km but since the materials are relatively dense, this study uses mass based transportation. No additional allocation was performed since all processes considered are single output systems for transportation. None of the systems are coupled and all of the calculated avoided emissions are associated with the relevant flows.

5.3. Data, data sources and data quality

The life cycle assessment (LCA) was initiated by Eastman with the input of LCA experts and supply chain representatives.

The LCA software GaBi version 6 service pack 27 was used to model the system, and the results presented use the 2015 GaBi database 6.110. The study complies with the WBCSD guidance Addressing the Avoided Emissions Challenge, though it was not 3rd party verified. More detail on the use of LCA at Eastman can be found at: http://eastman.com/Literature_Center/E/EMNST118.pdf.

a. Simplified calculation methodology:
   Since the solutions to compare differ only in the transportation phase of the life cycle of each product, a simplified avoided emissions calculation method is employed to reduce the complexity of the study. Manufacture, processing, and refining of all chemical remains unchanged whether or not AMS is used versus direct to customer conventional shipping. By omitting these life cycle stages, no claim can be made about how the total impact will change under the two solutions compared. No distinction is made between chemicals produced by Eastman Chemical Company or by any of its partners because the assumption is that these chemicals will be manufactured regardless of whether a bilateral agreement is in place. As mentioned in section 4. above, the functionality of the two solutions must be taken to be identical. The magnitude of the avoided emissions is compared to typical global warming potential for the products studied but the report does not attempt to report a reduction percentage in comparison to the reference solution.
b. The following LCA standards and references were used to guide this study. This report is not fully compliant with all of these standards. In particular, it has not been critically reviewed by external parties. An effort has been made to follow the standards as much as possible so that the extra work to fully comply could be efficiently done if Eastman decides to do so in the future.
   i. Addressing the Avoided Emissions Challenge version 2 (World Business Council for Sustainable Development.)
   ii. ISO 14040:2006
   iii. ISO 14044:2006
   iv. ILCD Handbook – General Guide for Life Cycle Assessment – Detailed Guidance (2010)
   v. GHG Protocol Product Lifecycle Accounting and Reporting Standard
   vi. Life Cycle Metrics for Chemical Products: A guideline by the Chemical Sector to assess and report product footprint. (World Business Council for Sustainable Development.)

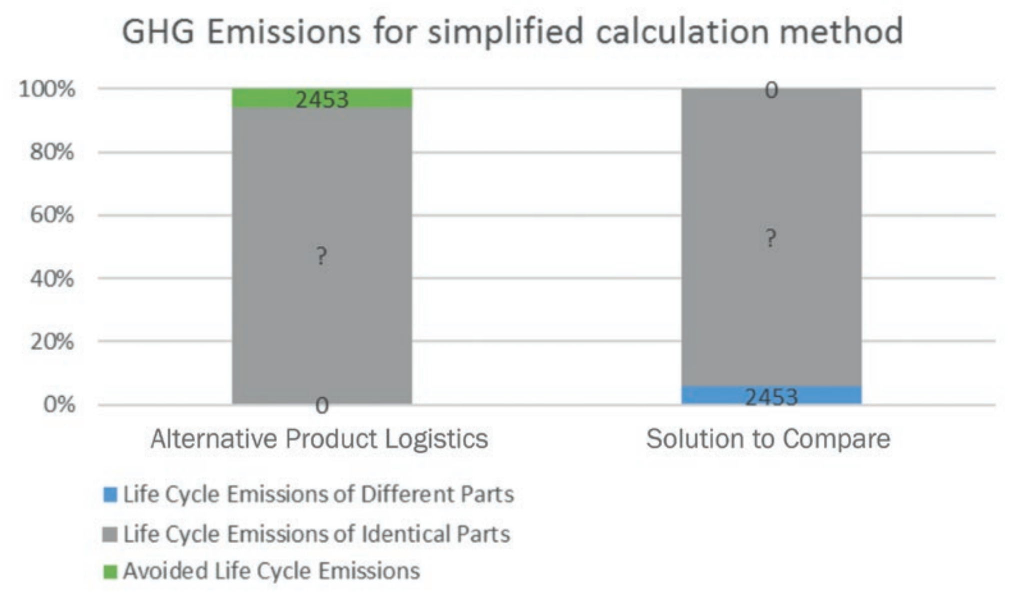
6. Results

6.1. Avoided emissions

The major finding of this study is that AMS does prevent significant and measurable greenhouse gas (GHG) emissions. For the yearlong period studied, an estimated 2,450 tonnes of CO_2 equivalent [1] were prevented from being emitted. As mentioned above, the simplified assessment has been used to calculate the difference between solutions.

[1] "CO_2-equivalent" GHG emissions are based on 2013 IPCC over a 100 year time horizon

FIGURE 5 - CARBON FOOTPRINT RESULTS FOR BILATERAL AGREEMENT – THE SOLUTION OF THE REPORTING COMPANY AVOIDS THE MARITIME SHIPPING LEG



The results in Figure 5 and Table 1 below show the impact of eliminating the maritime shipping leg of transportation.

TABLE 1 - AVOIDED EMISSION RESULTS

Emissions per stage (metric tons of CO_2e)	Reporting company's solution	Solution to compare to
Raw material extraction	-	-
Manufacturing / processing	-	-
Distribution	-	-
Maritime transportation	0	2453
Use stage	-	-
End of life	-	-
Total emissions	0	2453
Avoided emissions	2453	

TABLE 2 - WBCSD RECOMMENDED IMPACT INDICATORS FOR DIFFERENT MARINE SHIPPING MODES (PER T·KM)

Impact categories	Container ship	Transoceanic tanker
IPCC global warming, excl biogenic carbon [kg CO_2-Equiv.]	0.0143	0.00562
IPCC global warming, incl biogenic carbon [kg CO_2-Equiv.]	0.0143	0.00562
Acidification, accumulated exceedance [Mole of H+ eq.]	5.36E-04	1.59E-04
CML2001 2013, Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	3.86E-10	8.09E-10
CML2001 2013, Abiotic Depletion (ADP fossil) [MJ]	0.175	0.0760
CML2002 Resource Depletion, fossil, reserve Based [kg Sb-Equiv.]	1.36E-09	0
CML2002 Resource Depletion, mineral, reserve Based [kg Sb-Equiv.]	1.05E-09	2.02E-08
Ecotoxicity for aquatic fresh water, USEtox (recommended) [CTUe]	8.34E-04	0.00928
Freshwater eutrophication, EUTREND model, ReCiPe [kg P eq]	2.73E-09	1.06E-06
Human toxicity cancer effects, USEtox (recommended) [CTUh]	3.74E-12	2.26E-10
Human toxicity non-canc. effects, USEtox (recommended) [CTUh]	2.84E-10	5.33E-10
Marine eutrophication, EUTREND model, ReCiPe [kg N-Equiv.]	1.32E-05	1.75E-06
Ozone depletion, WMO model, ReCiPe [kg CFC-11 eq]	5.42E-14	6.38E-10
Particulate matter/Respiratory inorganics, [kg PM2,5-Equiv.]	2.53E-05	1.03E-05
Photochemical ozone formation, ReCiPe [kg NMVOC]	3.68E-04	4.89E-05
All impacts per t·km (tonne·kilometer)		

From marine shipping for yearlong period, Eastman would have shipped just under 24 thousand tonnes of chemicals overseas (the functional unit). The avoided emissions from the bilateral agreements totaled 2,453 tonnes of greenhouse gases.

6.2. Scenario Analysis

One scenario was examined to evaluate the impact of overland shipping. Model selection represents the biggest source of uncertainty, especially in overland shipping. The range for the “best case,” “most-likely,” and “worst case” scenarios for these models are presented in Table 3 and Table 4 below. Note that although only the global warming potential (GWP) is listed, other environmental impact indicators tend to track closely with GWP. Difference = sea + land – AMS. Conventional = sea + land.

This example also includes only one bilateral agreement though model selection would affect all bilateral agreements the same way. The worst case scenario assumes that trucks account for overland shipping whereas the likely scenario and best case scenarios both assume that overland shipping is via rail. According to the AMS division, about 90% of the overland shipping is via rail. Trucks are also more frequently used to transport goods from the Longview site to distribution centers or for urgent orders.

TABLE 3 - SCENARIOS COMPARING EASTMAN SHIPPING TO CUSTOMERS IN ITALY VERSUS A EUROPEAN COMPANY SHIPPING TO CUSTOMERS IN ITALY VIA DISTRIBUTION CENTER IN ROTTERDAM NL. SCENARIOS HIGHLIGHT THE IMPORTANCE OF SELECTING THE APPROPRIATE IMPACT FACTORS FOR TRANSPORTATION.

Mass (t)		1,557	1,557	1,557
		Best	Likely	Worst
kg/tkm	Impact Factor sea	0.0013	0.014	0.019
kg/tkm	Impact Factor land	0.022	0.074	0.093
km	Distance sea	10398	10398	10398
km	Rotterdam – partner company (AMS)	494	494	494
km	Kingsport – Houston (Conventional)	1703	1703	1703
t CO_2e/t	Impact AMS	0.0109	0.03651	0.0459
t CO_2e/t	Impact Conventional	0.0506	0.275	0.351
t CO_2e/t	Sea	0.0131	0.149	0.192
t CO_2e/t	Land	0.0375	0.126	0.158
Difference t CO_2e saved/t product shipped		0.040	0.24	0.30

TABLE 4 - THEORETICAL CASE IN WHICH EASTMAN SHIPS PRODUCT FROM KINGSPORT TO HOUSTON INSTEAD OF A EUROPEAN COMPANY SHIPPING TO HOUSTON FROM PARTNER COMPANY’S LOCATION. SCENARIOS HIGHLIGHT THE IMPORTANCE OF SELECTING THE APPROPRIATE IMPACT FACTORS FOR TRANSPORTATION.

Mass (t)		1,557	1,557	1,557
		Best	Likely	Worst
kg/tkm	Impact Factor sea	0.0013	0.014	0.019
kg/tkm	Impact Factor land	0.022	0.074	0.093
km	Distance sea	10398	10398	10398
km	Kingsport – Houston (AMS)	494	494	494
km	Rotterdam – partner company (Conventional)	1703	1703	1703
t CO_2e/t	Impact AMS	0.0375	0.126	0.158
t CO_2e/t	Impact Conventional	0.0240	0.185	0.238
t CO_2e/t	Sea	0.0131	0.149	0.192
t CO_2e/t	Land	0.0109	0.0365	0.0459
Difference t CO_2e saved/t product shipped [2]		(0.014)	0.059	0.080

2 This calculation is the difference between the conventional impact and the impact with AMS agreements. The net savings from AMS usually reduce the footprint of transportation, however model selection has a large impact on the amount of savings and as can be seen in the most efficient shipping scenario, the ship appears so much more efficient that its impact is less than the overland shipping method.

These tables show that there are substantially more avoided emissions from AMS activities when the modes of transportation are assumed to be relatively inefficient. When comparing different solutions, appropriate model choice is a major driver of results.

Using the two examples above, it is easy to see the differences in the solutions to compare in the bar graphs below in Figure 4. Since Eastman is free to choose AMS or conventional shipping only, Eastman's role is fundamental for claiming the avoided emissions for these products. The simplified calculation method was used here which shows only the differences in footprint and only accounts for the transportation stage of the life cycle of each product being compared; therefore, in the tables above and in the major results of the study, only the difference is reported. Figure 4 demonstrates that different models could drastically change the magnitude of the avoided emissions.

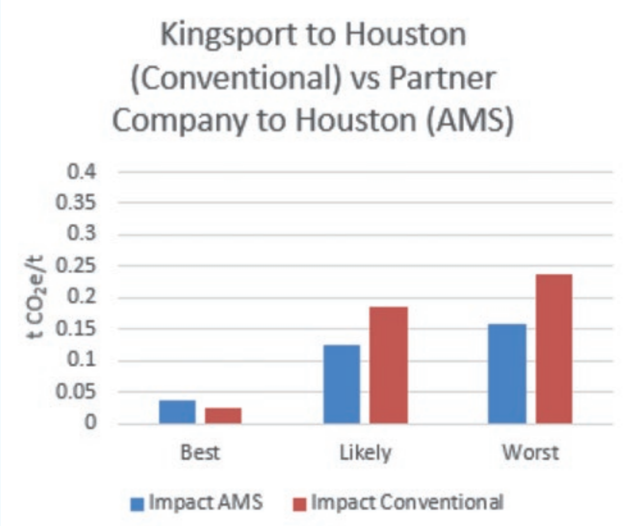
Comparing the solutions of conventional shipping vs alternate methods of supply, the study showed that Eastman can have a fundamental role in the value chain reducing emissions by employing bilateral agreements through alternative methods of supply. The avoided emissions can be significant, but the magnitude of the benefits are highly dependent on model selection within GaBi. The resulting large range of possible transportation scenarios still consistently show a benefit from bilateral agreements, even though uncertainties limit the definitiveness of any claim made.

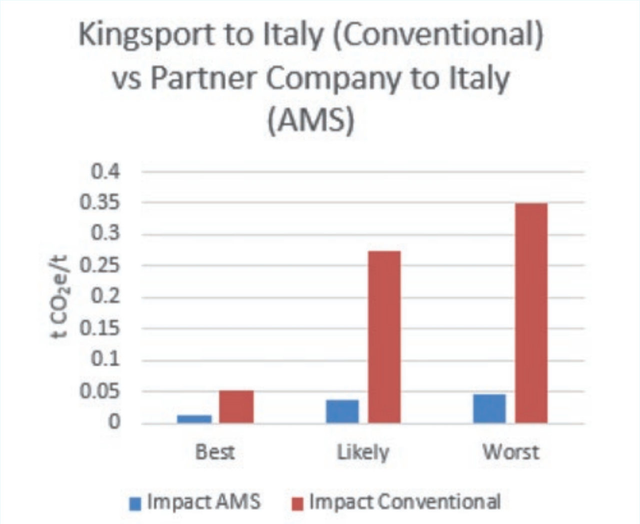
Overland shipping is involved in these agreements because it is necessary to transport goods to and from the major ports to which they are shipped. Overland shipping emissions can be significant but are not considered in this study for the reasons stated below:

1. Without AMS agreements, overland shipping is still necessary, just to and from different locations.
2. The relative impact of the AMS agreement on overland shipping depends on the locations of final customers compared to manufacturing locations. These vary significantly on a case by case basis, so while it may be valuable to add the overland shipping for a single bilateral agreement, no general conclusions can be drawn.
3. Even over an entire year, relatively few agreements are made. Without more data to develop an average, it would be difficult to make any reliable generalizations about the net positive or negative impact of bilateral agreements with respect to overland shipping.

The results of the scenario analysis presented in section 6.2 in Table 3 and Table 4 suggest that additional benefits associated with AMS bilateral agreements are caused by avoided overland shipping. That scenario is meant to serve as an illustration showing the potential impact of assumptions for overland shipping for a single agreement.

FIGURE 6 - SOLUTIONS TO COMPARE: CONVENTIONAL VS AMS BILATERAL AGREEMENTS UNDER DIFFERENT MODELING ASSUMPTIONS





7. Significance of contribution

The choice to use AMS bilaterial agreements is of fundamental significance to the avoided emissions for this solution. Bilateral agreements offer benefits to both companies involved in the deal, but for this analysis only the material produced by Eastman facilities is credited. Thus a similar fundamental avoided emission credit could be claimed by Eastman's partner companies' facilities in a way that would avoid double counting. Each agreement is different and so any allocation or attribution of avoided emissions should be stated explicitly for each case.

Treating this like a process improvement for production, all of the GHG savings remain with the chemical producer: either Eastman or the partner company. Thus Eastman's bilateral agreements (service) is fundamental to the avoided emissions seen in the supply chain.

8. Review of results

The study complies with the WBCSD guidance Addressing the Avoided Emissions Challenge, though it was not 3rd party verified. 3rd party verification could be sought if specific claims are being made about products in the marketplace or if greater accuracy is desired. This study's purpose is merely to show the major trend and probable impact of AMS activity. The study uses the simplified calculation method in the avoided emissions guidance.

9. Study limitations and future recommendations

Overland shipping is not included in these aggregated results due to the large possible range of results.

Eastman would either ship via container or chemical parcel tanker, but the magnitude of the impact from shipping is directly dependent on the model chosen. Some of the choices with respect to data set selection is discussed in detail in section 6 above.

For communication to potential partners, it is important to make clear that there is an environmental benefit associated with bilateral agreements in addition to the financial benefit which may provide additional incentive to participate in these agreements. It is also important to note that when engaging with a specific customer, the specific logistics involved with the bilateral agreement play a large part in the environmental benefit; thus this study should be used only as an aggregated assessment, and detailed work should be performed on a case-by-case basis.

Future work should be focused on narrowing the possible transportation models and validating the results of the models with other published empirical data.

10. Conclusions

Comparing the solutions of conventional shipping vs alternate methods of supply, the study showed that Eastman can have a fundamental role in the value chain reducing emissions by employing bilateral agreements through alternative methods of supply. The avoided emissions can be significant, but the magnitude of the benefits are highly dependent on model selection within GaBi. The resulting large range of possible transportation scenarios still consistently show a benefit from bilateral agreements even though uncertainties limit the definitiveness of any claim made.

This study is intended to reveal a novel way in which partners at the same level in the value chain can work together to save cost and reduce emissions at the same time. Each transaction is unique and the magnitude of avoided emissions varies on a case by case basis, but in some circumstances, significant savings can be realized.

11. References

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Case 14 Feed additives - DL-Methionine, L-Lysine, L-Threonine, L-Tryptophan and L-Valine in broiler and pig production

Evonik

COMMISSIONER AND PERFORMER OF THE STUDY

The study has been commissioned by the Evonik Segment Nutrition & Care GmbH, was conducted by the Evonik Life Cycle Management Group of Evonik Technology & Infrastructure GmbH and reviewed by the TÜV Rheinland LGA Product GmbH as an independent third party. The primary data for the study represents the situation in 2013.

1. Purpose of the study

This study assesses the reduction potential on environmental impacts (global warming including and excluding biogenic carbon, eutrophication and acidification) of the use of the 5 first limiting amino acids (DL-Methionine, L-Lysine, L-Threonine, L-Tryptophan and L-Valine) 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

For broiler feeding, four options were compared:

- **Four amino acids:** Supplementation of a defined premix consisting of the amino acids DL-Methionine, L-Lysine, L-Threonine and L-Valine
- **Rapeseed:** Supply of the respective amounts of amino acids by increasing the content of basic feed ingredients high in amino acids using rapeseed meal, which covers the European industrial practice on the use of locally produced oilseeds
- **SBM:** A second unsupplemented option using imported Soybean Meal (SBM) as protein rich feed ingredient
- **SBM incl. MetAMINO:** Feed mix based on SBM (Soybean Meal) but using DL-Methionine as the only amino acid supplementation

All four 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 4 amino acids MetAMINO®, Biolys®, ThreAMINO® and ValAMINO® with a corn basal diet
Option 2	Compound feed based on rapeseed meal without amino acid supplementation
Option 3	Compound feed based on SBM without amino acid supplementation
Option 4	Compound feed based on SBM only with MetAMINO® supplementation

For swine feeding, three options were compared:

- **Five amino acids:** Supplementation of a defined premix consisting of the amino acids DL-Methionine, L-Lysine, L-Threonine, L-Tryptophan and L-Valine
- **SBM:** Supply of the respective amounts of amino acids by increasing the content of basic feed ingredients high in amino acids using soybean meal
- **Rapeseed:** A second unsupplemented option covering the European industrial practice by using rapeseed meal as locally produced feed ingredient

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

FIGURE 2 - ALTERNATIVE OPTIONS FOR SWINE FEEDING

	Description
Option 1	Supplementation with the 5 amino acids MetAMINO®, Biolys®, ThreAMINO®, TrypAMINO® and ValAMINO® 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, respectively four options for livestock production to cover the nutritional demand of the target animal 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 2014 the overall compound feed market for all species was published at 980,000 Kmt. Provided a proper application of DL-Methionine, supplemented option 1 reflects 350,000 Kmt (around 35 %) against 630,000 Kmt (65 %) non supplemented feed in option 2, for Biolys (L-Lysine) option 1 reflects 420,000 Kmt (around 43 %) against 560,000 (57 %) non supplemented feed in option 2 and finally for Threonine option 1 reflects 400,000 Kmt (around 43%) against 580,000 Kmt (around 57 %) 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 seems 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, tryptophan and valine are the five 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, Tryptophan and also Valine 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 and are converted easily into fat 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 (FU), common to all compared solutions to make them comparable in terms of GHG emissions, was defined as 1 kg of an amino acid mix consisting of DL-Methionine, L-Lysine, L-Threonine, L-Tryptophan and L-Valine 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, L-Tryptophan and L-Valine 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 2013. 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 L-Valine (based on assumptions made with pilot productions for the technical evaluation), 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, L-Tryptophan and L-Valine 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 FOR BROILER PRODUCTION

Feed raw materials, kg	Option 1 "4 amino acids"	Option 2 "Rapeseed"	Option 3 "SBM"	Option 4 SBM incl. MetAMINO®
Wheat		106.08	77.42	67.59
SBM		0.41	22.56	9.60
Soya oil		14.79	7.83	4.71
Extracted rapeseed meal		37.99		
Corn		–156.93	–106.29	–80.96
Dicalciumphosphate		–0.76	–0.23	–0.18
$CaCO_3$		–0.33	–0.10	–0.03
Salt		–0.08	–0.05	–0.05
Sodium carbonate		0.05	0.05	0.05
Amino acids				
MetAMINO® (99.0 %)	0.61			0.48
Biolys (54.6 % L-Lysine)	0.46			
ThreAMINO® (98.5 %)	0.10			
ValAMINO® (98.0 %)	0.05			
Emissions g				
g NH_3	31.54	1251.44	971.78	530.59
g N_2O	0.66	26.34	20.45	11.17
g NO_x	1.44	57.27	44.47	24.28
g NO_3	19.46	771.93	599.43	327.29
Credit for mineral fertilizer				
g N	10.89	432.08	335.52	183.20

FIGURE 4 - LIFE CYCLE INVENTORY FOR SWINE PRODUCTION

Feed raw materials, kg	Option 1 "5 amino acids"	Option 2 "SBM"	Option 3 "Rapeseed"
Wheat		−11.93	−31.12
Barley		−17.44	−1.24
SBM, 48 % CP		23.24	21.87
Extracted rapeseed meal			3.23
Corn-DDGS		11.72	11.72
Soya oil		−1.34	−4.34
Rapeseed oil			4.09
Dicalciumphosphate		−0.24	−0.17
$CaCO_3$		−2.28	−2.37
Salt		−0.25	−0.26
Amino acids			
MetAMINO® (99.0 %)	0.15		
Biolys® (54.6 % L-Lysine)	1.05		
ThreAMINO® (98.5 %)	0.25		
TrypAMINO® (98.0 %)	0.02		
ValAMINO® (98.0 %)	0.02		
Emissions g			
g NH_3	26.79	640.22	652.88
g N_2O	1.77	42.29	43.12
g NO_x	5.41	129.28	131.84
g NO_3	27.48	656.61	669.61
Credit for mineral fertilizer			
g N	26.68	637.55	650.17

TABLE 1 - CALCULATED FEED MIXES FOR BROILER PRODUCTION

Feed raw materials, kg	Option 1 "4 amino acids"	Option 2 "Rapeseed"	Option 3 "SBM"	Option 4 "SBM incl. MetAMINO®"
Wheat		41.89	30.57	26.69
SBM	29.10	29.26	38.01	32.89
Soya oil	5.15	10.99	8.24	7.01
Extracted rapeseed meal		15.00		
Corn	61.97		20.00	30.00
Dicalciumphosphate	1.64	1.34	1.55	1.57
$CaCO_3$	0.75	0.62	0.71	0.74
Premix Blank Poultry	0.50	0.50	0.50	0.50
Salt	0.31	0.28	0.29	0.29
Sodium carbonate	0.10	0.12	0.12	0.12
Amino acids				
MetAMINO® (99.0 %)	0.24			0.19
Biolys® (54.6 % L-Lysine)	0.18			
ThreAMINO® (98.5 %)	0.04			
ValAMINO® (98.0 %)	0.02			

TABLE 2 - DIET OPTIONS GROWER PHASE 1 FOR SWINE PRODUCTION

Feed raw materials, kg	Option 1 "5 amino acids"	Option 2 "SBM"	Option 3 "Rapeseed"
Wheat	45.05	41.01	25.22
Barley	30.75	11.95	24.03
SBM, 48% CP	10.83	26.18	24.25
Extracted rapeseed meal			
Corn-DDGS	2.92	15.00	15.00
Soya oil	4.27	3.63	
Rapeseed oil			4.53
Vit. Min. Premix	0.50	0.50	0.50
Dicalciumphosphate	0.58	0.36	0.41
$CaCO_3$	3.85	1.24	1.15
Salt	0.19	0.12	0.12
Amino acids			
MetAMINO® (99.0%)	0.13		
Biolys® (54.6% L-Lysine)	0.71		
ThreAMINO® (98.5%)	0.17		
TrypAMINO® (98.0%)	0.01		
ValAMINO® (98.0%)	0.03		

TABLE 3 - DIET OPTIONS GROWER PHASE 2 OF SWINE PRODUCTION

Feed raw materials, kg	Option 1 "5 amino acids"	Option 2 "SBM"	Option 3 "Rapeseed"
Wheat	45.05	43.49	14.60
Barley	39.22	15.02	40.00
SBM, 48% CP	8.20	22.07	20.38
Extracted rapeseed meal			3.99
Corn-DDGS		15.00	15.00
Soya oil	1.51	2.34	
Rapeseed oil			3.98
Vit. Min. Premix	0.50	0.50	0.50
Dicalciumphosphate	0.50	0.25	0.35
$CaCO_3$	3.89	1.20	1.08
Salt	0.21	0.13	0.11
Amino acids			
MetAMINO® (99.0%)	0.11		
Biolys® (54.6% L-Lysine)	0.65		
ThreAMINO® (98.5%)	0.15		
TrypAMINO® (98.0%)	0.01		
ValAMINO® (98.0%)	0.02		

TABLE 4 - DIET OPTIONS GROWER PHASE 3 OF SWINE PRODUCTION

Feed raw materials, kg	Option 1 "5 amino acids"	Option 2 "SBM"	Option 3 "Rapeseed"
Wheat	45.05	31.50	31.50
Barley	40.00	40.00	40.00
SBM, 48% CP	1.80	18.04	18.04
Extracted rapeseed meal			
Corn-DDGS	6.39	7.46	7.46
Soya oil	3.33	1.16	
Rapeseed oil			1.16
Vit. Min. Premix	0.50	0.50	0.50
Dicalciumphosphate	0.26	0.19	0.19
$CaCO_3$	1.28	0.99	0.99
Salt	0.43	0.17	0.17
Amino acids			
MetAMINO® (99.0%)	0.08		
Biolys® (54.6% L-Lysine)	0.71		
ThreAMINO® (98.5%)	0.17		
TrypAMINO® (98.0%)	0.01		
ValAMINO® (98.0%)	0.001		

4. Boundary setting

The system boundaries for all scenarios equivalent to the 3, resp. 4 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 1-6 provide 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 ANALYZED IN BROILER AND SWINE FEEDING

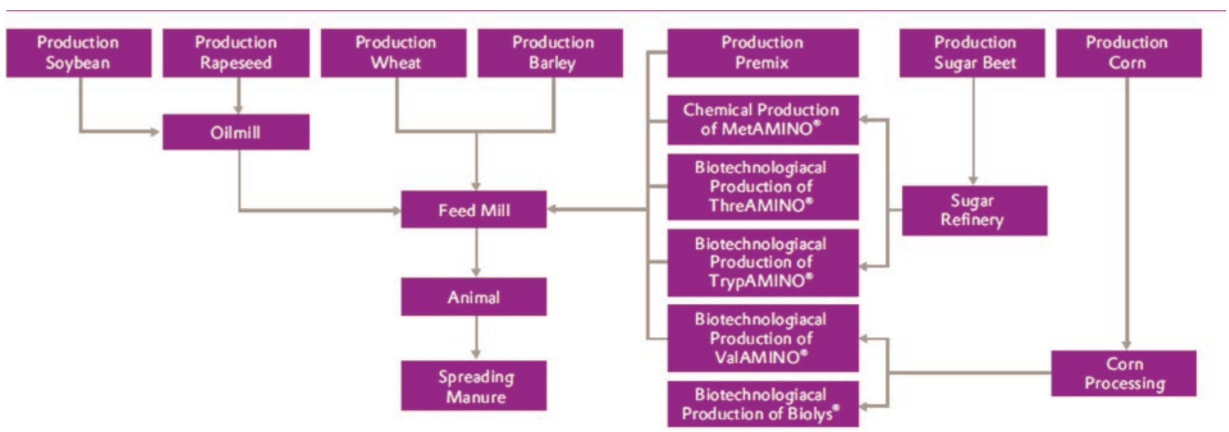
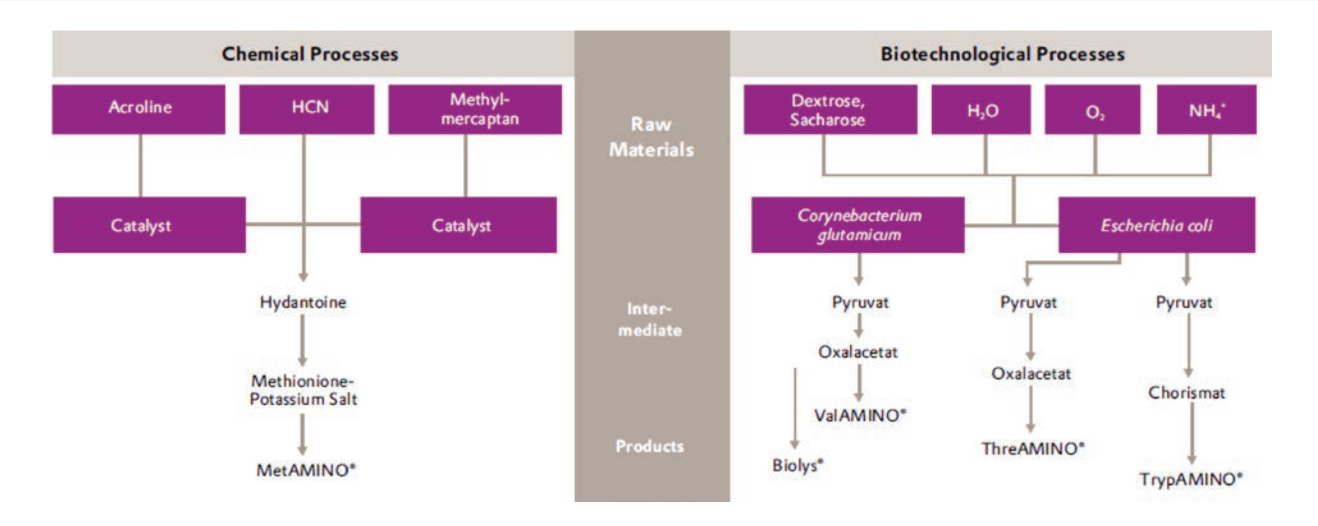


FIGURE 6 - RELEVANT MATERIAL FLOW AND RAW MATERIALS FOR THE RESPECTIVE TYPE OF MANUFACTURING



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 by 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 impact categories for the specific application of amino acids in animal nutrition:

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

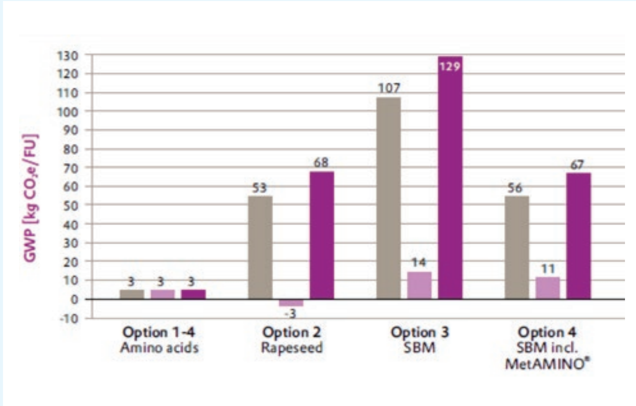
The environmental impact categories GWP, AP and EP have been evaluated using the CML-methodology[1] with updated characterization factors of April 2013 (IPCC 2007). In quantification of the global warming potential the inclusion of land use change (LUC) for soya production in South America has a very strong influence on the results. That's why a sensitivity analysis has been conducted. It was assumed for the evaluation that about 52.9%[5] of soya in South America is grown on land that originally was rain forest. No land use change was considered for the 3 % of soy bean meal (SBM) imported from the US and for the 33% of soy bean oil (SBO) imported from Russia. 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 line with the earlier study from 2010, the aspect of LUC was evaluated again in the current study. This topic has gained increasing popularity and importance in the discussion on renewable raw materials for biofuels and bio based products during the last years. This was the reason why this aspect was again integrated in the LCA study. Additionally, there is reliable scientific data on LUC available. The base scenario assumed as a reference situation for soya production in South America included a certain extent of LUC and the value was set at 52.9 % (share of land impacted by the land use change). In the sensitivity analysis a varying percentage of soya grown in the respective regions was studied. Indirect LUC was not considered as the methodology and mode of calculation is still the subject of scientific discussions.
In this study an average LUC for soybean cultivation from Brazil and Argentina has been assumed. As the area where LUC occurs is individually different, a sensitivity analysis was performed to outline the individual impact LUC emissions might have on overall GWP results. In the sensitivity analysis "LUC soya" the portion of soya from land which had undergone LUC was set to 0% (minimum) in case no LUC occurred, and to maximum values of 58.6 % for Brazil and 70.4 % for Argentina. This value has been calculated based on data of soybean cultivation in Brazil and Argentina from FAOStat[5]. This model affects the two data sets "soybean meal" and "soybean oil". The import split i. e. the portion of SBM from the USA, Brazil, and Argentina remained unchanged.

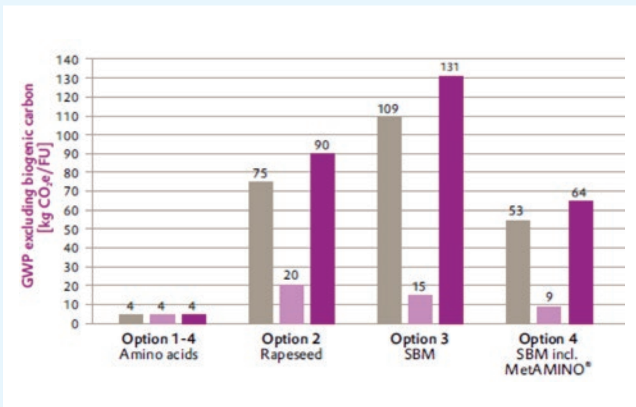
The land use change primarily affects emissions relevant for the climate factors which then has an impact on GWP (see Figures 7 and 8). The major effect is caused by the degradation of biomass stored in the soil releasing the CO_2 fixed in the soil. Additional information can be found in the documentation of PE Int. and the sources cited in there[12].

FIGURE 7 - GLOBAL WARMING POTENTIAL, INCLUDING BIOGENIC CARBON[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 FU for this option. The GWP for option 1 remains unchanged accordingly at a level of 3 kg CO_2e/FU. Assuming no direct LUC emissions at all in option 2, the GWP reduces by approx. 56 kg CO_2e to a level of – 3 kg CO_2e/FU while increasing the area of LUC brings GWP to a level as high as 68 kg CO_2e/FU. The corresponding values for option 3 vary between 14 kg and 129 kg CO_2e/FU, and for option 4 between 11 kg and 67 kg CO_2e/FU respectively.
Assuming no LUC for soybean cultivation can refer to a better performance in GWP for option 2. This seems to be reasonable as biotechnological production of amino acids is an energy intensive process compared to crop production. Including biogenic carbon the background dataset for rapeseed meal shows a lower carbon footprint than for soybean meal even without any emissions from LUC. Thus, using rapeseed instead of SBM leads to a reduced overall GWP result.

FIGURE 8 - GLOBAL WARMING POTENTIAL, EXCLUDING BIOGENIC CARBON[CML 2001] FROM BROILER PRODUCTION – SENSITIVITY ANALYSIS FOR "LAND USE CHANGE SOYA"



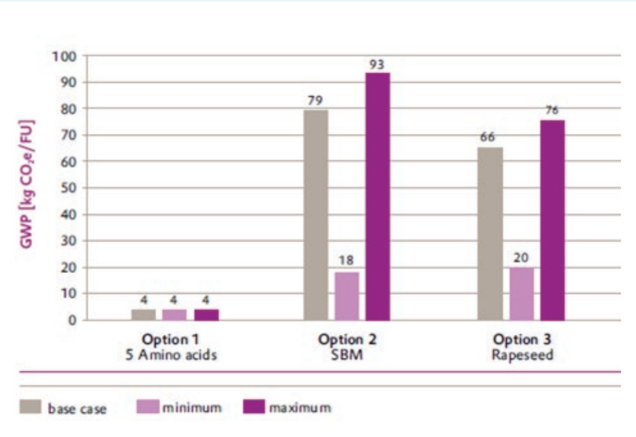
Biogenic carbon is usually part of the natural carbon circle as it is taken up by crops and plants during growth and emitted during further production processes or end-of-life of products and biomass. Emissions from

LUC are assumed to be not part of that circle anymore in which they are emitted additionally when compared to the biological amount of carbon needed for plant growth. LUC emissions resulting from conversion of carbon rich vegetation areas to cropland with lower carbon stock are often much higher than the amount that can be taken within a short time period (Figure 8). Thus, LUC emissions are in the atmosphere and contribute to the greenhouse effect. That is why emissions from LUC are treated as fossil carbon dioxide and the results therefore show similar characteristics to GWP results including biogenic carbon.

Swine production - Sensitivity analysis "land use change soya"

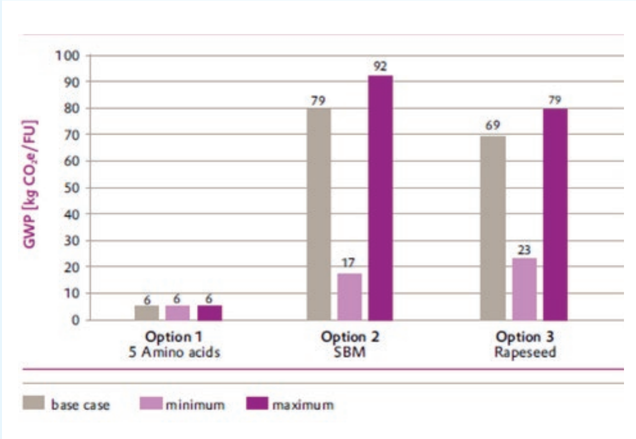
The same approach of land use change calculation and the variation of parameters for broiler production were also applied for swine production. The LUC primarily affects emissions relevant for the climate factors which in turn has an impact on GWP (see Figure 9 and 10). The major effect is caused by the degradation of biomass stored in soil releasing the CO_2 fixed in the soil. Additional information can be found in the documentation of PE International and the sources cited in there.

FIGURE 9 - GLOBAL WARMING POTENTIAL, INCLUDING BIOGENIC CARBON [CML 2001] FOR SWINE PRODUCTION – SENSITIVITY ANALYSIS "LAND USE CHANGE SOYA"



The range assumed for soya does not have an impact on the scenario of option 1 as no SBM is included in the FU for this option. The GWP for option 1 remains unchanged at a level of 4 kg CO_2e/FU. Assuming no direct LUC in South America at all, option 2 reduces GWP by approx. 61 kg CO_2e to a level of 18 kg CO_2e/FU while increasing the amount of LUC brings GWP to a level as high as 93 kg CO_2e/FU. The corresponding values for option 3 vary between 20 kg and 76 kg CO_2e/FU.

FIGURE 10 - GLOBAL WARMING POTENTIAL, EXCLUDING BIOGENIC CARBON [CML 2001] FOR SWINE PRODUCTION – SENSITIVITY ANALYSIS "LAND USE CHANGE SOYA"



As explained before, carbon dioxide emissions from LUC are considered as fossil CO_2 emissions. Therefore, the results show similar characteristics to GWP results including biogenic carbon again (Figure 10).

5.2. Allocation

Allocation of by-products was made by value (= mass • price) in internally modeled processes. This is the case for those amino acids with by-products which are sold to external customers such like MetAMINO® and ThreAMINO®.
For those by-products that cannot be sold to externals no allocation was made and all environmental impacts were ascribed to the main product. As many datasets for agricultural raw materials from PE International also include allocations on an economic basis, the modeling procedure is consistent for the amino acids production, as well. Some database processes use different forms of allocation, e. g. based on mass, energy content or stoichiometric ratios. Reference is made to the corresponding dataset documentations (PE International 2014, EcoInvent 2008). In a few cases energy is produced within separate production steps. In these cases credits were given for the appropriate energy type because this energy is used in other production process on integrated sites.

5.3. Data sources and data quality

The primary data for the production of the five amino acids represent the situation in 2013. 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 5 - ORIGIN OF PROCESS DATA FOR BROILER PRODUCTION

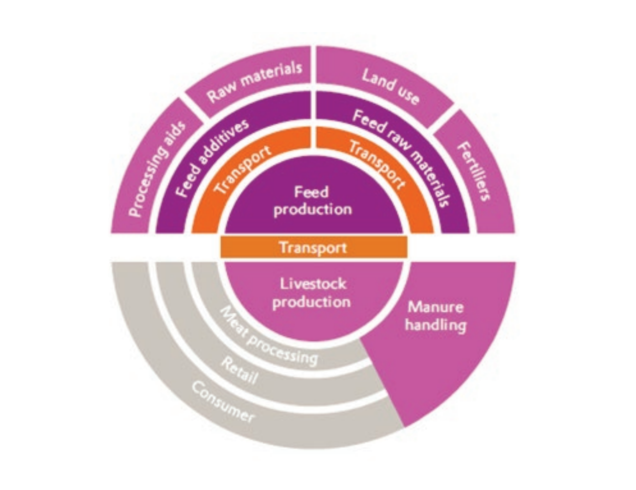
Process	Origin and reference period	Data source
DE: Soybean meal import mix (partly with LUC, 2013)	Individual data sets: PE Int. 2014, Import mix: Evonik (taken from statistics for 2013)	secondary
DE: Soybean oil import mix (partly with LUC, 2013)	Individual data sets: PE Int. 2014, Import mix: Evonik (taken from statistics for 2013)	secondary
EU-27: Rapeseed meal (wet mill) (economic allocation) PE	Individual data sets: PE Int. 2014	secondary
DE: Corn grains, at field (15% H_2O)	Individual data sets: PE Int. 2014	secondary
DE: Winter wheat grains (mass) PE	Individual data sets: PE Int. 2014	secondary
DE: Dicalcium phosphate (estimation) PE	Individual data sets: PE Int. 2010	secondary
DE: Limestone ($CaCO_3$; washed) PE	Professional data base, PE Int. 2014	secondary
DE: Sodium chloride (rock salt) PE	Professional data base, PE Int. 2014	secondary
DE: Soda (Na_2CO_3)	Professional data base, PE Int. 2014	secondary
BE: MetAMINO®	Evonik: based on process data 2013	primary
US: Biolys®	Evonik: based on process data 2014	primary
HU: ThreAMINO®	Evonik: based on process data 2013	primary
SK: ValAMINO®	Evonik: based on process data 2013	primary
_transport land (lorry) DE	Professional data base, PE Int. 2013,also including fuel supply datasets from professional database, PE Int. 2013	secondary
_transport sea (ocean ship, bulk) EU-27	Professional data base, PE Int.2013, also including fuel supply datasets from professional database, PE Int. 2013	secondary
EU-27: Ammonium nitrate PE	Professional data base, PE Int. 2013	secondary
DE: Mix Poultry XXX- total N emissions from slurry of poultry fattening	Evonik (according to IFEU 2004)	secondary

TABLE 6 - ORIGIN OF PROCESS DATA FOR SWINE PRODUCTION

Process	Origin and reference period	Data source
DE: Soybean meal import mix (partly with LUC, 2013)	Individual data sets: PE Int. 2014, Import mix: Evonik (taken from statistics for 2013)	secondary
DE: Soybean oil import mix (partly with LUC, 2013)	Individual data sets: PE Int. 2014, Import mix: Evonik (taken from statistics for 2013)	secondary
EU-27: Rapeseed meal (wet mill) (economic allocation) PE	Individual data sets: PE Int. 2014	secondary
DE: Canola (rapeseed) oil PE	Individual data sets: PE Int. 2014	secondary
DE: Winter wheat grains (mass) PE	Individual data sets: PE Int. 2014	secondary
DE: Spring barley grains (14% H_2O, 12% RP) PE	Individual data sets: PE Int. 2014	secondary
US: DDGS (Allocation-Model, +DDGS with burden) PE	Individual data sets: PE Int. 2010	secondary
DE: Limestone ($CaCO_3$; washed) PE	Professional data base, PE Int. 2014	secondary
DE: Sodium chloride (rock salt) PE	Professional data base, PE Int. 2014	secondary
DE: Dicalcium phosphate (estimation) PE	Individual data sets: PE Int. 2010	secondary
BE: MetAMINO®®	Evonik: based on process data 2013	primary
US: Biolys	Evonik: based on process data 2014	primary
HU: ThreAMINO®	Evonik: based on process data 2013	primary
SK: TrypAMINO ®	Evonik: based on process data 2013	primary
SK: ValAMINO®	Evonik: based on process data 2013	primary
_transport land (lorry) DE	Professional data base, PE Int. 2013,also including fuel supply datasets from professional database, PE Int. 2013	secondary
_transport sea (ocean ship, bulk) EU-27	Professional data base, PE Int., also including fuel supply datasets from professional database, PE Int. 2013	secondary
EU-27: Ammonium nitrate PE	Professional data base, PE Int. 2013	secondary
DE: Mix Swine XXX- total N emissions from slurry of poultry fattening	Evonik (according to IFEU 2004)	secondary

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 coloured segments highlight a close proximity of factors to the business of the sponsor. The darker the colour the larger the influence. More primary data are available here.

FIGURE 11 - 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 12 - GLOBAL WARMING POTENTIAL, EXCLUDING BIOGENIC CARBON GWP100 [CML 2001] FOR BROILER PRODUCTION

Avoided Emissions	Avoided Emissions (Option 2 – Option 1)	Avoided Emissions (Option 3 – Option 1)	Avoided Emissions (Option 4 – Option 1)
Global warming potential, excluding biogenic carbon GWP100 [1] in kg CO_2eq/functional unit	71	105	49

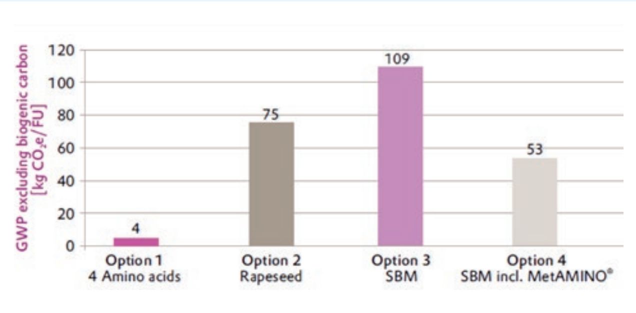
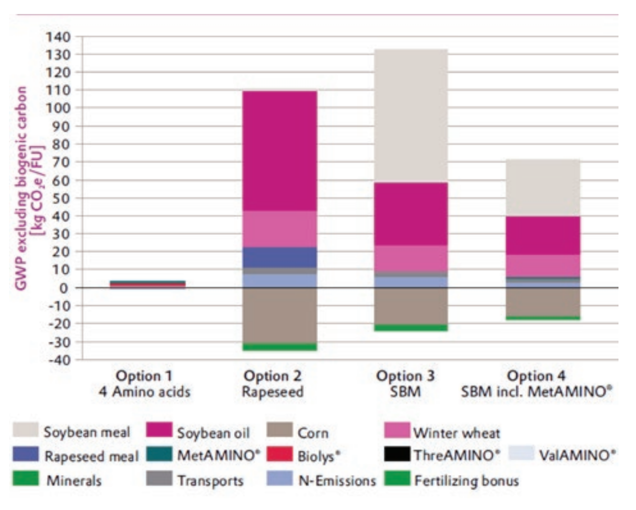


FIGURE 13 - GLOBAL WARMING POTENTIAL, EXCLUDING BIOGENIC CARBON GWP100 [CML 2001] FOR BROILER PRODUCTION BROKEN DOWN BY CONTRIBUTIONS OF INDIVIDUAL FACTORS

Emissions	Option 1 (Evonik's solution)	Option 2 (Solution to compare)	Option 3 (Solution to compare)	Option 4 (Solution to compare)
Global warming potential, excluding biogenic carbon GWP100 [1] in kg CO_2eq/functional unit	4	75	109	53



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 oil. The supplemented feed mix in option 1 uses less winter wheat compared to option 2 and therefore results in a lower GWP excluding biogenic carbon. In contrast, the supplemented feed mix in option 1 uses more corn compared to option 2 and therefore results in a negative GWP value of avoided corn for option 2. In total, the effect of avoided wheat and soybean oil of option1 leads to a lower GWP of the supplemented feed mix in option 1 compared to option 2, 3 and 4.

Swine production

FIGURE 14 - GLOBAL WARMING POTENTIAL GWP100 [CML 2001] FOR 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	73	63

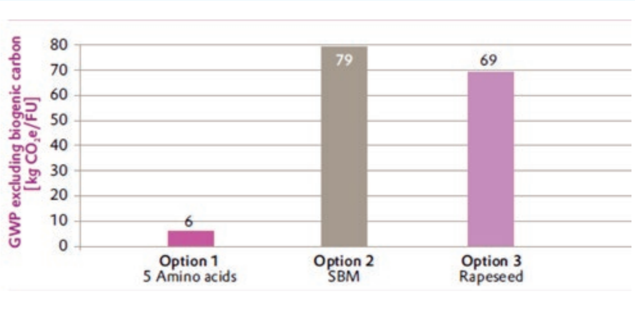
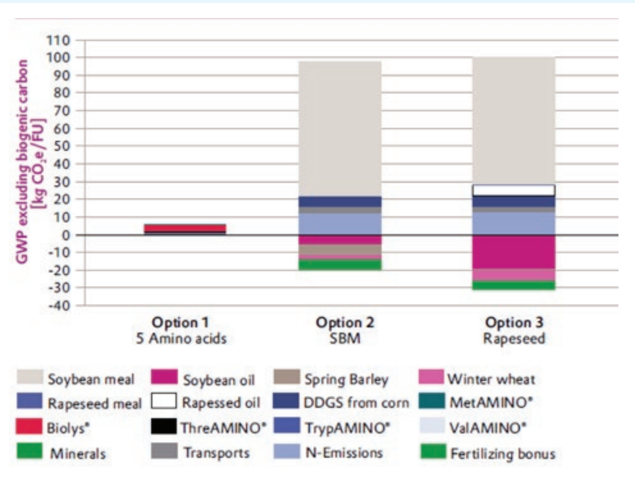


FIGURE 15 - GLOBAL WARMING POTENTIAL, EXCLUDING BIOGENIC CARBON GWP100 [CML 2001] FOR SWINE PRODUCTION BROKEN DOWN BY INDIVIDUAL CONTRIBUTIONS OF FACTORS

Emissions	Option 1 (Evonik's solution)	Option 2 (Solution to compare)	Option 3 (Solution to compare)
Global warming potential, excluding biogenic carbon GWP100 [1] in kg CO_2eq/functional unit	6	79	69



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 parameter for the greenhouse gas reduction compared to option 2 is soybean meal. The supplemented feed mix in option 1 uses more sping barley and soybean oil compared to option 2 represented in the negative credits of option 2.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. In total, the effect of substituting soybean meal leads to a lower GWP of the supplemented feed mix in option 1.

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, as defined by the ICCA/WBCSD guidance, to the avoided greenhouse gas emissions.

8. Review of results

The study has been reviewed by the German TÜV Rheinland in 2015 and recertified in 2017. Further information on the review can be found at https://www.certipedia.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, including biogenic carbon (GWP100) [kg CO_2eq according to IPCC 2007]
- Global warming potential, excluding biogenic carbon (GWP100) [kg CO_2eq]
- 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 in chemical synthesis and in biotechnological fermentation since 2008. On the other hand, the modelling process was further developed and more transparent data sets are available from environmental databases. Additionally the study outlines also that the advanced inclusion level of crystalline amino acids to animal diets further leads to environmental savings.

11. References

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12. Appendices

Report of the main results other than GHG emissions

Broiler production

FIGURE 16 - ACIDIFICATION POTENTIAL AP [CML 2001] OF BROILER PRODUCTION

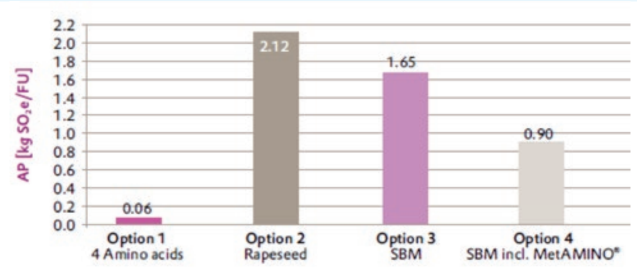


FIGURE 17 - EUTROPHICATION POTENTIAL EP [CML 2001] OF BROILER PRODUCTION

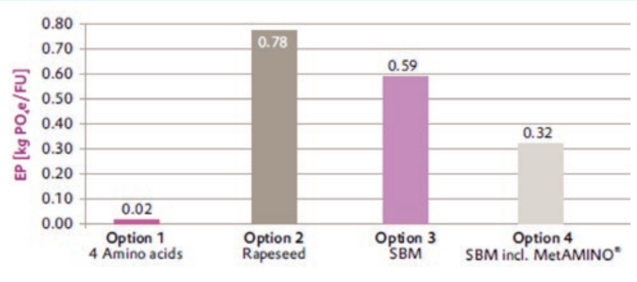


FIGURE 18 - PRIMARY ENERGY DEMAND (PED) OF BROILER PRODUCTION

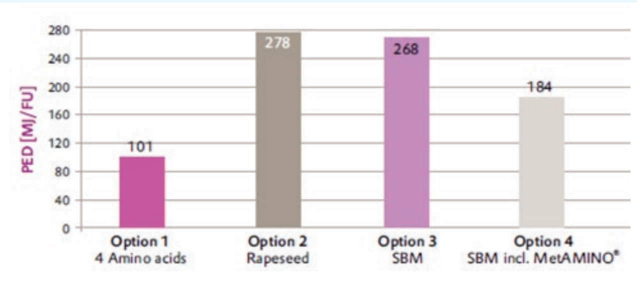
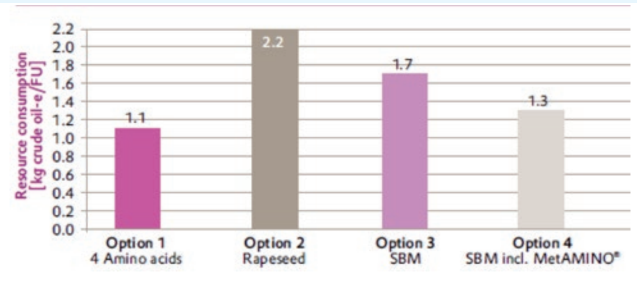


FIGURE 19 - RESOURCE CONSUMPTION OF BROILER PRODUCTION



Emissions	Option 1 (Evonik's solution)	Option 2 (Solution to compare)	Option 3 (Solution to compare)	Option 4 (Solution to compare)
Acidification potential AP [1] in kg SO_2e/functional unit	0.06	2.12	1.65	0.90
Eutrophication potential EP [1] in PO_4e/functional unit	0.02	0.78	0.59	0.32
Primary energy demand PED in MJ/functional unit	101	278	268	184
Resource consumption in kg crude oil equi./functional unit	1.1	2.2	1.7	1.3

Swine production

FIGURE 20 - ACIDIFICATION POTENTIAL AP [CML 2001] OF SWINE PRODUCTION

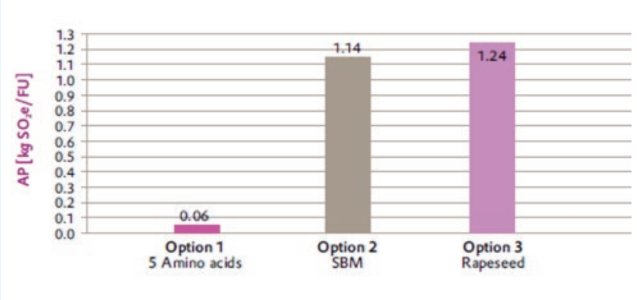


FIGURE 21 - EUTROPHICATION POTENTIAL EP [CML 2001] OF SWINE PRODUCTION

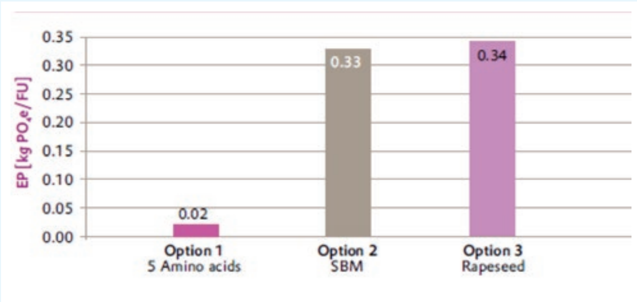


FIGURE 22 - PRIMARY ENERGY DEMAND (PED) OF SWINE PRODUCTION

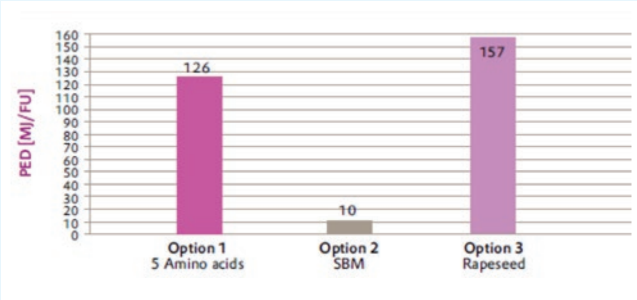
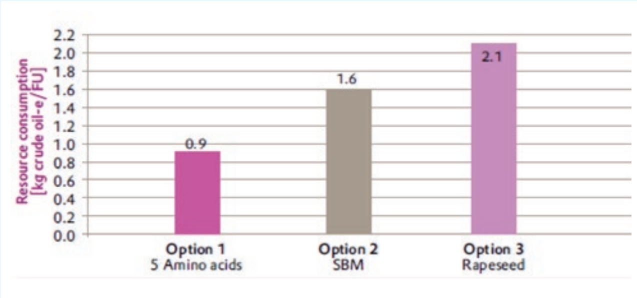


FIGURE 23 - RESOURCE CONSUMPTION OF SWINE PRODUCTION



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	0.06	1.14	1.24
Eutrophication potential EP [1] in PO_4e/functional unit	0.02	0.33	0.34
Primary energy demand PED in MJ/functional unit	126	10	157
Resource consumption in kg crude oil equi./functional unit	0.9	1.6	2.1

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)	Avoided Emissions (Option 4 – Option 1)
Acidification potential AP [1] in kg SO_2e/functional unit	2.06	1.59	0.84
Eutrophication potential EP [1] in PO_4e/functional unit	0.76	0.57	0.30
Primary energy demand PED in MJ/functional unit	177	167	83
Resource consumption in kg crude oil equi./functional unit	1.1	0.6	0.2

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	1.08	1.18
Eutrophication potential EP [1] in PO_4e/functional unit	0.31	0.32
Primary energy demand PED in MJ/functional unit	-116	31
Resource consumption in kg crude oil equi./functional unit	0.7	1.2

Case 15 Renewable Polyethylene based on Hydro treated Vegetable Oil (HVO) diesel – avoided emissions perspective

SABIC

COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned by SABIC, performed by SABIC and reviewed by Quantis.

1. Purpose of the study

The objective of the study is to quantify, from life cycle perspective, greenhouse gas (GHG) emissions of polyethylene produced using hydro treated vegetable oil (HVO) diesel as a feedstock for steam cracking. HVO is produced from hydro treating of vegetable oils and animal fats. Waste animal fats represent the non-edible by-product from meat processing and hence does not interfere with human food chain. Likewise, palm oil fatty acid is a by-product produced during refining of crude palm oil.

1.1. Methodology used

This study has been aligned with 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.

Since this study involves feedstocks of biogenic origin, rigorous and consistent carbon accounting for this study was considered to be essential. Biogenic carbon accounting for the renewable routes were made based on PAS 2050 specification [11].

1.2. Other relevant high-level information

The coverage of emissions related to carbon footprint for all three product systems is believed to be at a good level for reliable quantification. Carbon balance was performed for each process step and all unaccounted carbon from the carbon balance was assumed to be emitted as carbon dioxide to ensure closure of the balance. This is a realistic approach for the chemical process industry as all hydrocarbon emissions (with the exception of process leaks and purges) are typically converted to carbon dioxide prior to their release to the atmosphere.

2. Solutions to compare to

This LCA study capture the flow of material and energy corresponding to the production of polyethylene resin from polymerization of ethylene. Ethylene feedstock is produced using three different precursors:

a. HVO diesel using animal fats, by-product from meat processing facility
b. HVO diesel using palm oil fatty acids, by-product from palm oil production
c. Fossil naphtha derived from refining of crude oil.

As defined in this guideline revision, avoided emission comparisons fall into the following three categories:

Category 1, where the reference product is the non-use of a product or technology;
Category 2, where the reference product or technology is from another sector (for a chemical product the reference product is a non-chemical product or technology);
Category 3, that compares products or technologies within the same sector (for chemical industry the reference product is another chemical product).

This assessment based on comparison of polyethylene produced from renewable and conventional fossil routes falls in Category 3.

2.1. Description of the solutions to compare

It is assumed that all three routes will produce same grade of polyethylene resin with very comparable functional properties. Hence polyethylene produced from all three routes are expected to demonstrate equivalent performance in use stage, including comparable service lives. Ethylene (feedstock for polyethylene production) of comparable purity and quality is assumed to be produced from all three routes under comparison.

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

The study is based on generic polyethylene resin (thus intended for any application) and the end-of-life assumptions are based on average statistics for waste plastics in European region. Hence it is assumed that the end products made using SABIC Renewable Polyethylene will be produced and consumed within the European region.

2.3. All aspects of the emissions generated during the life cycle

This study quantifies carbon removals and emissions throughout the life cycle. In the case of animal fats route, this includes emissions during life of the livestock besides emissions that occur during meat processing, conversion of animal fat to HVO diesel, cracking of HVO diesel to produce ethylene and subsequent polymerization of ethylene to polyethylene. In the case of palm oil route, changes in carbon stocks due to land use changes is included as a sensitivity case.

2.4. Description of the usage of chemical product as part of the end-use application (if the case study is conducted at end-use level)

As described in previous sections of this report, this study is based on production of generic polyethylene resin and not intended for any specific product application. Since polyethylene resin of equivalent functional attributes is produced from all three routes, plastic processing (conversion of resin into finished products, of defined properties, form and shape) and use stage of the end-use application are omitted from this assessment. Since the polymer resin produced is expected to be highly comparable or of identical properties and purities for all three routes, this omission is consistent with ICCA/WBCSD Guidelines (2013).

3. Functional unit and reference flow

3.1. Description of the function and the functional unit

3.1.1. Description of the function and functional unit

Since polyethylene resin does not deliver any one specific function (typically used for varied applications such as rigid and flexible packaging, pipes, etc.,) this is not applicable for this study. Product use stage is not modelled in this study.

3.1.2. Functional unit of the product

Choice of functional unit is critical as it represents a reference flow of the product system that delivers the same function as other product alternatives used in the comparison. In this assessment, one kilogram of polyethylene has been selected as the functional unit for this assessment. This approach ensures modularity for future extensions of the study for several specific product applications.

3.2. Reference flow

The reference flow is based on 1 kilogram of 100% generic polyethylene resin with no inclusion of any additives or fillers as the study is not restrictive to any product application.

3.3. Quality requirements

The assessment assumes generic polyethylene resin of equivalent functional attributes for all three routes under comparison. Product quality characteristics are out of context, as end-use of product is not modelled in this study for all three alternatives under comparison.

3.4. Service life

Since end-use of products are not considered and comparison of the three alternative routes for making polyethylene is made only at resin level, service life is assumed to be zero. Carbon storage in durable products is also out of context.

3.5. Time and geographic reference

Primary data related to steam cracking of HVO diesel is based on SABIC internal data from 2012. Data for upstream processes are based on the most updated datasets from Biograce [15] and Ecoinvent v2.2 available at the time of the study.

This study models production and consumption of polyethylene in Europe. All upstream processes and functions related to product systems under evaluation, with the exception of palm oil fatty acids (that are assumed to be sourced from Malaysia) are assumed to be carried out within Europe. End-of-life scenarios of post-consumer polyethylene are also based on statistics for European Union. Hence the results of this study are expected to be fairly representative of Europe.

4. Boundary setting

As described earlier in the report, three different routes for production of polyethylene are being compared in this assessment. Life cycle schematic for each of the three systems under comparison are presented below separately (Figures 4.1, 4.2 and 4.3).

FIGURE 4.1. - PRODUCT SYSTEM SCHEMATIC – VIA HVO DIESEL (ANIMAL FATS) ROUTE

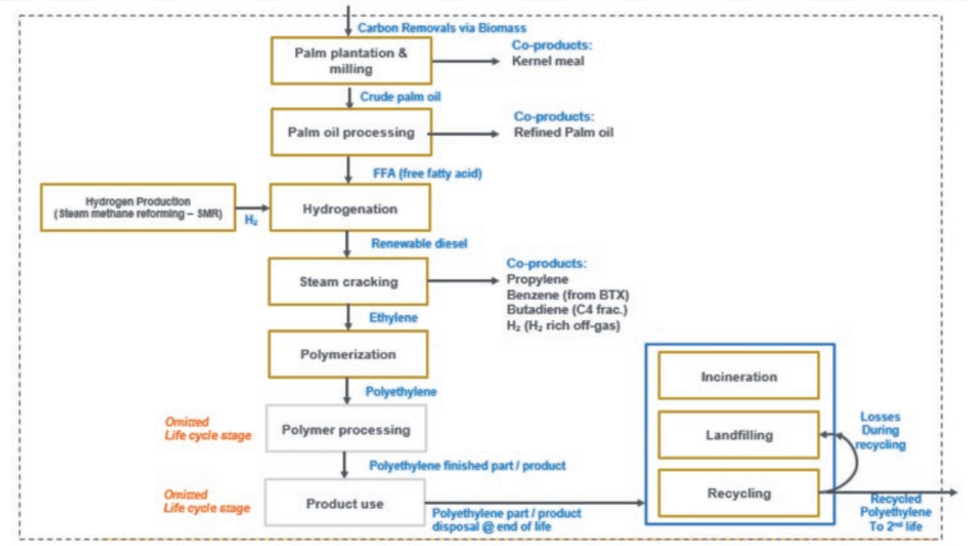


FIGURE 4.2. - PRODUCT SYSTEM SCHEMATIC – VIA HVO DIESEL (PALM OIL) ROUTE

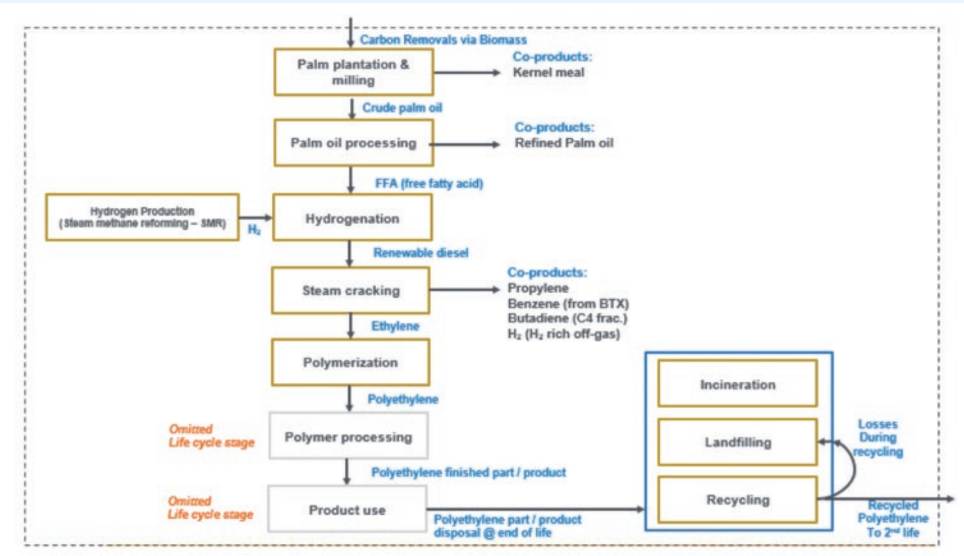
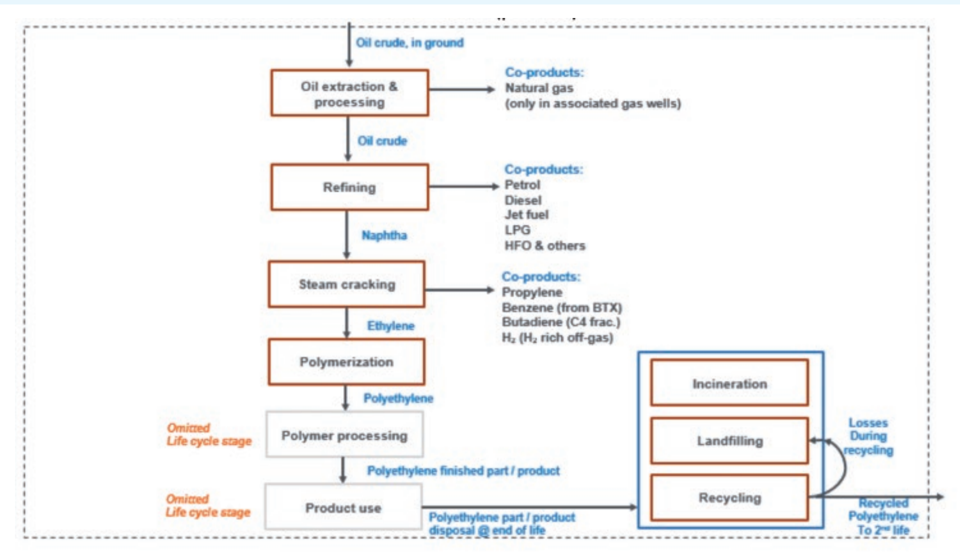


FIGURE 4.3. - PRODUCT SYSTEM SCHEMATIC – VIA FOSSIL NAPHTHA ROUTE



5. Calculation methodology

5.1. Methods/formulas used

Based on PAS 2050 Specification for biogenic carbon accounting the following rules apply (as was considered in this study):

Emissions associated with incineration of waste materials, wherein such systems are equipped for energy recovery is considered to be zero for the product system. Whenever energy is produced from such systems, all emissions and removals (biogenic carbon sequestration) arising as a result of the activity are attributable to the energy generating system. Along the same lines, all biogenic carbon emissions and removals linked to the mass fraction of plastics that are recycled at end-of-life are attributable to the second life of the waste plastic.

5.2. Allocation

Table below captures the choices made in this study on allocation for various multi-output processes:

TABLE 6.1. - ALLOCATION CHOICES FOR VARIOUS MULTI-OUTPUT PROCESSES

S. No.	Process:	Description of co-products:	Allocation basis:
1	Production of Animal fats	Multi-output process that delivers meat products, food grade byproducts apart from C1 & C3 waste animal fats.	Economic allocation
2	Palm oil processing	Multi-output process that delivers kernel meal and crude palm oil.	Energy content
3	Palm oil refining	Multi-output process that delivers Refined Palm oil and FFA (Free Fatty Acids).	Energy content
4	Steam cracking of HVO diesel	Multi-output process that delivers ethylene, propylene, mixed C4 olefins, BTX, H_2 rich off-gas and Methane rich off-gas	Mass - HVC (High Value Chemicals)
5	Steam cracking of Fossil Naphtha	Multi-output process that delivers ethylene, propylene, mixed C4 olefins, BTX, H_2 rich off-gas and Methane rich off-gas	Mass - HVC (High Value Chemicals)
6	Hydrogen production via Steam methane reforming	Multi-output process that delivers hydrogen and carbon monoxide.	Energy content

5.3. Data sources and data quality

Primary data related to steam cracking of HVO diesel are based on SABIC internal data from 2012. Inventory data related to HVO diesel production and upstream processes for palm oil cultivation and processing are based on Biograce database. Data for upstream (livestock rearing) and meat processing facilities is based on report published by Hans Blonk (2009). End-of-life scenarios assumed by the base case are based on statistics for European Union in 2008 as published by Bio Intelligence Services report for European Commission (2009. The inventory data used by the study is believed to be at a good level for assessment of impacts related to carbon footprint.

5.4. Key parameters of the study

For palm oil based route to renewable polyethylene, capture of methane emissions that arise during palm oil processing (as a result of anaerobic digestion of palm oil mull effluent) is a critical parameter that can significantly influence the results of the study. For other routes, there are no such critical parameters.

5.5. Scenarios used (if applicable)

Key scenarios being explored in this study are related to carbon footprint for palm oil based route to polyethylene: base scenario assumes only 5% methane capture in palm oil mills (based on reported average statistics published in 2014). Alternative scenario assumes 100% methane capture as a best-case scenario. Also, the impacts due to Direct Land use change induced by new palm oil cultivation is also explored as a sensitivity case.

6. Results

6.1. Report of the main results

TABLE 6.1. - CRADLE TO GRAVE RESULTS

Life cycle phase:	Cradle to Grave Carbon footprint (All are in kgCO2 eq. / kg Polyethylene resin) Method: IPCC GWP 100a			
	Petroleum Naphtha based Generic Polyethylene	Animal fats based Renewable Polyethylene	Palm oil Fatty acids based Renewable Polyethylene (5% methane capture)	Palm oil Fatty acids based Renewable Polyethylene (100% methane capture#)
Feedstock production *	0.68	-1.88	1.46	-0.81
Manufacture **	1.18	1.13	1.13	1.13
Plastic processing	*Comparable (Not modelled to keep study generic)*	*Comparable (Not modelled to keep study generic)*	*Comparable (Not modelled to keep study generic)*	*Comparable (Not modelled to keep study generic)*
Use of end-product	*Comparable (Not modelled to keep study generic)*	*Comparable (Not modelled to keep study generic)*	*Comparable (Not modelled to keep study generic)*	*Comparable (Not modelled to keep study generic)*
Disposal / recycling ***	-0.24	-0.24	-0.24	-0.24
Overall	1.62	-1.00	2.35	0.08

** Feedstock production for animal fats route includes Life of livestock, meat processing & Renewable Diesel production*
** Feedstock production for Palm oil route includes Palm oil plantation, Palm oil processing & Renewable Diesel production*
** Feedstock production for Petroleum naphtha route includes Oil crude refining for production of naphtha*
*** Manufacturing step for all three routes include Ethylene production via steam cracking & Polyethylene production via Polymer*
**** Disposal / Recycling assumes 21.3% Recycling, 48.7% Landfilling & 30% Incineration (with energy recovery)*
 # Based on reported statistics, only about 5% methane is captured in Palm oil mills globally [10]

TABLE 6.2 - CRADLE TO GATE RESULTS

Life cycle phase:	Cradle to Gate Carbon footprint (All are in kgCO2 eq. / kg Polyethylene resin) Method: IPCC GWP 100a			
	Petroleum Naphtha based Generic Polyethylene	Animal fats based Renewable Polyethylene	Palm oil Fatty acids based Renewable Polyethylene (5% methane capture)	Palm oil Fatty acids based Renewable Polyethylene (100% methane capture#)
Feedstock production *	0.68	-3.44	-2.37	-0.10
Manufacture **	1.18	1.13	1.13	1.13
Overall	1.86	-2.31	-1.23	1.03

** Feedstock production for animal fats route includes Life of livestock, meat processing & Renewable Diesel production*
** Feedstock production for Palm oil route includes Palm oil plantation, Palm oil processing & Renewable Diesel production*
** Feedstock production for Petroleum naphtha route includes Oil crude refining for production of naphtha*
 # Based on reported statistics, only about 5% methane is captured in Palm oil mills globally [10]

Supplementary note on key difference between "Cradle to Gate" & "Cradle to Grave" analysis:

Acc. to PAS2050 standards, all carbon removals attributable to portion of waste plastic that is recycled or incinerated (with energy recovery) is passed on to the 2nd life of recycled plastic & energy generating system respectively. This would imply credit for carbon removals of 0.3+0.197 kg of waste plastic that is incinerated & recycled are passed over to the respective life cycles & not claimed as part of current life cycle. However, in "Cradle to Gate" all carbon removals attributable to 1kg of waste plastic plus removals attributable to additional feedstock required to produce 1kg plastic are fully credited to the current product system.

6.2. Avoided Emissions

The avoided emissions are calculated as the difference between "Cradle to Grave" carbon footprint for production of 1 kg generic polyethylene produced via conventional petroleum naphtha route and each of the renewable based routes.

It is key to note that the "Cradle to Grave" carbon footprint for animal fats route is negative overall implying net sequestration of biogenic carbon from atmosphere. This would imply that a calculated difference of carbon footprint between petroleum naphtha route animal fat route will result in a difference that includes both avoidance of fossil based emissions plus removals due to biogenic feedstock.

Calculations are presented below for avoided emissions calculations based on animal fats route and palm oil route with 100% methane capture. Since "Cradle to Grave" carbon footprint of palm oil with 5% methane capture is higher than that of conventional route, the same is not included below (as such a route is not believed to enable any avoided CO_2 emissions):

Animal fats route:
Avoided CO_2e emissions per kg polyethylene: (1.62-(- 1.00)) = 2.62 kgCO_2 eq.

Palm oil route (with 100% methane capture):
Avoided CO_2e emissions per kg polyethylene: (1.62-0.08) = 1.54 kgCO_2 eq.

The new SABIC product of Renewable Polyethylene is based on animal fats based HVO diesel as a feedstock. Animal fats is a non-edible by-product from meat processing and hence does not interfere with human food chain. Calculations based on projected avoided emissions are presented below for every 1000 tonnes of Renewable Polyethylene:

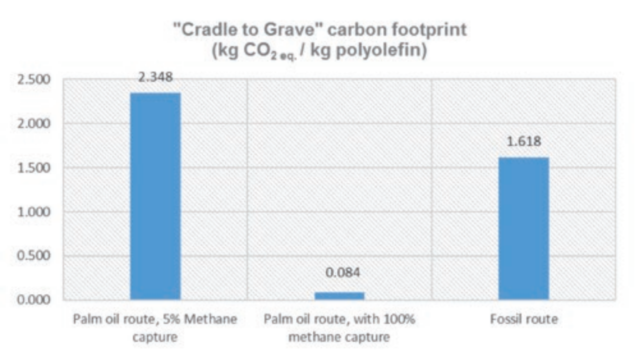
Avoided CO_2e emissions per tonne of Renewable Polyethylene based on animal fats:
= (1.62-(-1.00)) = 2.62 tonnes CO_2 eq.

Avoided CO_2e emissions per 1000 tonnes of Renewable Polyethylene based on animal fats:
(1.62-(-1.00))*1000 = 2620 tonnes CO_2 eq.

6.3. Scenario analysis

Carbon footprint results based on extended scenario of 100% methane capture by palm oil mills conclude that palm oil based route to renewable polyethylene can be associated with lesser GHG emissions when compared to petroleum naphtha route. This emphasizes on key areas for improvement for policy development in the future.

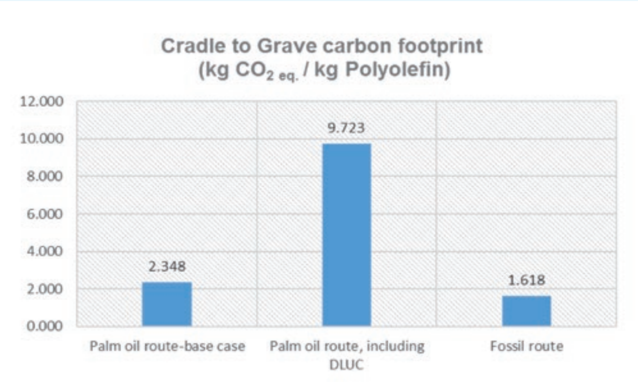
FIGURE 6.1. - SENSITIVITY ANALYSIS – IMPACTS DUE TO METHANE CAPTURE DURING PALM OIL PROCESSING



Although the base case study assumes no impacts due to Land use change as the HVO diesel is assumed to use palm oil fatty acid feedstock from palm plantations that are associated with sustainable practices, a sensitivity analysis is included here in an assumed scenario of impacts due to land use change.

Based on statistics reported by Malaysia Palm oil board [16], about 2.9 million hectares of additional area of land has been planted for palm oil cultivation during the period between 1990-2010. This would imply that about 59% of the total area planted for palm oil cultivation is linked to Direct land use change (D-LUC). Also, based on analysis of historical statistics of land use changes in Malaysia as well as projections of future land use changes by Birka et. al. (2011) [12], it may be a combination of land used for other permanent crops and forest as well as degraded lands that may undergo the highest conversions to land for oil palm cultivation. As a conservative case, this scenario analysis explores impacts on GHG emissions due to Direct land use change. These calculations are performed based on PAS2050 guidelines [11, 14].

FIGURE 6.2 - SENSITIVITY ANALYSIS – IMPACTS DUE TO DIRECT LAND USE CHANGES CAUSED BY NEW PALM OIL CULTIVATION



Note: 59% of the land used for Palm oil cultivation is assumed to be linked to D-LUC (Direct land use change)

7. Significance of contribution

Polyethylene produced via animal fats route, the product of interest assessed in this study, makes extensive contribution to reduction of GHG emissions since this is enabled within the SABIC operations by switching of naphtha with HVO diesel as feedstock for production of ethylene via steam cracking.

8. Review of results

The detailed LCA study (based on which this abridged case study was developed) underwent external critical review by Dr. Adisa Azapagic and team (University of Manchester). However detailed results of the main study are outside the scope of this report.

9. Study limitations and future recommendations

The authors target to improve the coverage of other environmental impacts in a future extension of this work as more complete emissions data related to steam cracking and polyethylene production becomes available for the product systems under consideration. However, at this point of time, this is not expected to be restrictive for carbon footprint.

10. Conclusions

Based on the above results for the study, it is quite evident that polyethylene production based on waste animal fats can lead to substantial avoided emissions. Palm oil based route may have avoided emissions potential but only in the case of 100% or near 100% methane capture. However, significant trade-offs do exist for palm oil route (in terms of water depletion, fresh water eutrophication and land occupation). The significance of contribution of the chemical product (polyethylene in this case) to value chain avoided emissions is assessed to be "extensive". Use of renewable feedstocks towards production of polymers that are recyclable at end-of-life is a good example of circular economy concept and it can provide important advantages in terms of GHG mitigation. Attribution of this avoided emission benefit to value chain partners was not carried out for this assessment since certain life cycle stages were not modelled for this generic study, but authors believe that this is a key topic in need of industry consensus that can enable wider adoption as well as bring in transparency and consistency in reporting of avoided emissions.

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Case 16 Double-glazed windows in buildings and contribution of sodium carbonate in avoiding greenhouse gas emissions

Solvay

COMMISSIONER AND PERFORMER OF THE STUDY

The study has been commissioned by Solvay Soda Ash business, performed by Solvay Research & Innovation (Jean-François VIOT*), with the contribution of AGC Glass Europe (Guy Van Marcke de Lummen** & Tiago David da Cruz**), and reviewed by Quantis.

1. Purpose of the study

The objective of this study is to quantify the reduction in greenhouse gas (GHG) emissions resulting from the use of double glazing in replacement of existing single-glazing for windows, in Europe.

In particular, the study aims at highlighting the contribution of Solvay's synthetic sodium carbonate (also called soda ash), a key chemical in glass manufacturing, in the reduction of energy consumption, and the subsequent reduction of GHG emissions from houses. Indeed, nowadays, quantities of synthetic sodium carbonate are produced in order to face the demand from the glass industry for producing high performance double-glazing to replace existing single-glazing in windows in the renovation market in Europe. That demand is driven by the mega-trend of energy saving that has taken place in building management for some years.

This study is conducted 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 (2013, revised 2017) developed by the Chemical Sector Group of the WBCSD and with ICCA.

2. Solutions to compare

2.1. Description of the solutions to compare

The study compares a double-glazing with a single-glazing element, both fulfilling the same functions, but with different thermal conductivity. The study encompasses the full life cycle of the two versions of that element.

Focus on thermal conductivity

The replacement of single-glazing by double-glazing in windows is aiming at reducing the energy needed to keep the houses warm. This replacement may take place either upon entire renovation of the houses, or on-purpose when the renovation is limited to replacing the glazing or the window(s).

Such replacement ensures better thermal insulation of houses through a lower thermal conductivity, thanks to the layered system glass-gas-glass constituting the double-glazing element.

The present study focusses on the glazing alone. The impact of the frame and its connection to the building is not taken into account as it is independent from the replacement of the glazing.

Air conditioning excluded

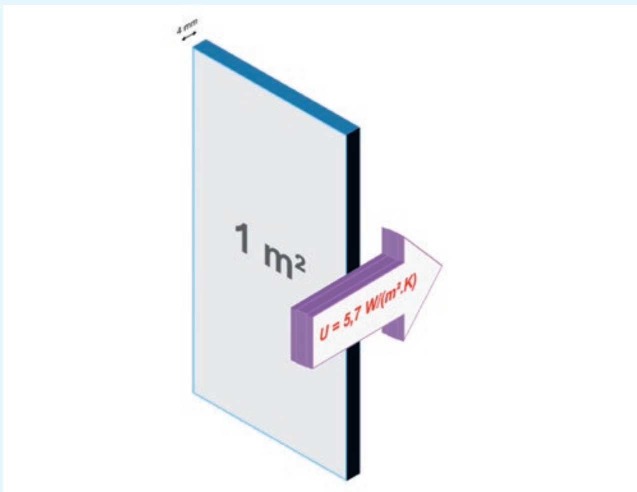
Only heating and the resulting GHG emissions are considered: cooling by air conditioning devices, and the resulting energy consumption and GHG emissions are outside the scope of this study. Such an assumption is pertinent since air conditioning is not common in most European houses. Note that a more complex modelling would have been necessary for energy consumption due to air-conditioning if commercial buildings would have been included in the scope of the study (see § 2.2 for precise definition of the market boundaries).

Accordingly, the two versions of window glazing to be compared are defined as follows:

Version 1 (solution to compare to): single glass window glazing

1 m² of a single glass, 4 mm thick, providing a thermal transmission (U-value) of 5.7 W/(m².K) (figure 1).

FIGURE 1 - STRUCTURE OF A SINGLE GLARING UNIT



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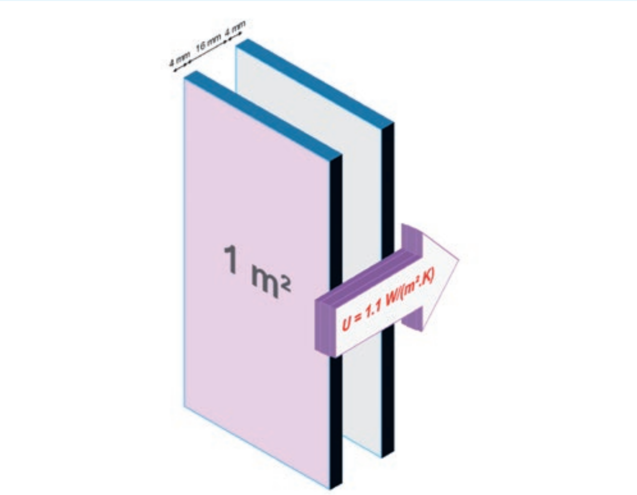
Version 2 (solution of the reporting company): double glass window glazing

1 m² of a double-glazing, 4 mm of glass with low-e [1] coating, 16 mm of sealed inert gas (Argon : 90%) and dry air (10%), 4 mm of glass (4-16-4), providing a U-value of 1.1 W/(m².K) (figure 2).

FIGURE 2 - STRUCTURE OF A TYPICAL DOUBLE GLAZING UNIT WITH A U VALUE OF 1.1 W/M².K.



2.2. Boundaries of the market and application

The considered market in this study is the replacement of single-glazing by high performance double-glazing in housing buildings in Europe (see 3.5 - Time and geographic reference of the study - for details), within the frame of building renovation. The considered effect is the reduction of thermal losses through the window glazing obtained by substituting single-glazing by double-glazing in windows on the energy consumption necessary to heat the houses, and the consequent reduction of GHG emissions.

The emission savings are calculated for a 30 years period, typical reference service life (RSL) of double-glazing, (see prEN 17074).

3. Functional unit and reference flow

3.1. Functional unit

The "functional unit" (the considered "service") of both solutions must be the same for the 2 solutions to be compared. Therefore, calculations are based on the same functional unit: 1 m² of glazing (prEN 17074), with the following constraints: (1) allowing similar lighting entering the house and (2) ensuring a 20°C inside temperature.

(It is considered that the same quantity of light enters the house with the 2 solutions to compare. In other words, the same window surface is needed in order to ensure the same quantity of light entering the house).

3.2. Reference flow

The "reference flow" is the mass of products that are necessary to manufacture 1 m² of glazing (corresponding to the selected functional unit). This mass will determine the greenhouse gas emissions associated with the manufacturing of the 2 solutions to be compared.

Calculation of the reference flow

Glass density: 2.5 kg/dm³
Glass composition (simplified, according to EN 572-1) (Table 1)

TABLE 1 - COMPOSITION RANGE OF THE TYPICAL SODA LIME SILICATE FLOAT GLASS USED IN BUILDING, ACCORDING TO EN 572-1

	from	to
Silicon dioxide ($Si0_2$)	69%	74%
Calcium oxide (CaO)	5%	12%
Sodium oxide (Na_20)	12%	16%
Magnesium oxide (MgO)	0%	6%
Aluminium oxide (Al_203)	0%	3%

In order to reach the right composition, the raw materials

- synthetic sodium carbonate (Na_2CO_3)
- Sand (SiO_2)
- Carbonates (dolomite, limestone)
- Etc.

are mixed in the following average weight ratio, in this study e.g.:

Sand	62%
Synthetic sodium carbonate	19%
Dolomite	16%
Limestone	3%

They are then introduced in a high temperature furnace (> 1,500°C) in the adequate ratios; they are melted and transformed in an amorphous transparent solid while CO_2 is emitted as a by-product of the chemical reaction that takes place.

Version 1 (solution to compare to):

Weight for 1 m² of one glass plate with a thickness of 4 mm:

1 (m²) x 0.004 (m) x 2.5 (kg/dm³) x 1,000 (dm³/m³) = 10 kg of glass

1 Low-e = low emissivity.

Losses due to glass handling and cutting being at about 10% (estimation based AGC Glass Europe's experience), a total of

11 kg of glass

is necessary to be produced to manufacture 1 m² of single-glazed surface with a thickness of 4 mm.

Remark: The overall yield at glass manufacture step is very high. Losses of raw materials at that step are included in the 10% above mentioned

On this basis, the consumption of raw materials for the manufacture of 1 m² of glass plate, 4 mm thick is:

Sand	6.82 kg
Synthetic sodium carbonate	2.09 kg
Dolomite	1.76 kg
Limestone	0.33 kg

Version 2 (reporting company solution):

Weight for 1 m² of 2 glass plates with a thickness of 4 mm:

$2 \times 1\ (m^2) \times 0.004\ (m) \times 2.5\ (kg/dm^3) \times 1000\ (dm^3/m^3) =$ 20 kg of glass

For the same reasons as above, a total of

22 kg of glass

is necessary to be produced to manufacture 1 m² of double-glazed surface (4-16-4), requiring the following raw materials:

Sand	13.64 kg
Synthetic sodium carbonate	4.18 kg
Dolomite	3.52 kg
Limestone	0.66 kg

3.3. Quality requirements of the solutions to compare

Both types of glazing offer the performance in terms of bringing daylight into the house and of quality. They are thus, as required in such a study, fully exchangeable, except for the level of thermal insulation. All other functions are identical and fulfilled with at least the same level of performance for the double-glazed window as for the single-glazed window.

3.4. Service life of the solution

The new solution: double-glazing is considered to have a reference service life (RSL) of 30 years as per prEN 17074.

3.5. Time and geographic reference of the study

The geographic reference of the study is glazing replacement in Europe, considering 7 different climate zones / conditions.

The time reference is the period 2015-2045, (30 years of reference service life for the new double-glazing, installed in Europe in year 2015).

4. Boundary setting

Life cycle steps

For both solutions, the considered life cycle steps are the following in accordance with EN 15804:

1. production of glass ingredients;
2. processing of glass (in accordance with the functional unit, with the window frame and casing outside the system boundaries) into the double glazing unit;
3. use stage: contribution of the glazing to heat loss (through their specific thermal conduction).

End of life is not considered due to a very low contribution to GHG emissions over the entire life cycle of both types of glazing (When not landfilled, glass is either grinded and mixed with other construction and demolition wa ste to be used as common construction material or recycled into glass, mostly for packaging and fibres).

The installation of the glazing in houses are not considered neither since it is supposed to generate very low GHG emissions and that it can be considered as similar for the 2 solutions to compare.

Geographical scope

This study considers the potential for glazing replacement in Europe. For every zone, distinct climate conditions (determining the energy losses via the glazing) and energy mixes (determining the GHG emissions due to house heating) are considered, and then aggregated (weight average).

Europe is divided into 6 zones (figure 3):

1. North (Helsinki)
2. Central Maritime (Brussels)
3. Central Continental (Frankfurt)
4. Central (Prague)
5. South Central (Sofia)
6. South (Roma)

FIGURE 3 - SITUATION OF THE SIX CLIMATIC ZONES ACROSS EUROPE AS CONSIDERED IN THIS STUDY

5. Calculation methodology and data

5.1. Methods and formulas

- **Production stage: production of ingredients and of glass**
  See 5.3
- **Use stage**

GHG emissions that are attributable to heat losses via the glass surfaces during the use stage of their life cycle result from the heat generation necessary to compensate these losses.

Heat losses are due to the thermal transmission through the glazing. It is considered that between the "solution to compare to" and the "reporting company solution", only the glazing varies. All other elements of the buildings and means of heating are considered identical as regards energy dispersion or conservation.

The computation of energy consumption for house heating (and the consequent GHG emissions) is based on hypotheses representative of each of the 7 zones presented above and then aggregated. It takes into account:

- Distribution for the outside temperatures (meteorological data),
- Energy mix for the heating devices for housing buildings.

Energy consumptions are calculated for a typical house in each climate zone.

5.2. Allocation

No allocation to by-products has been applied in modelling the foreground data and particularly in modelling sodium carbonate production: All greenhouse gas emissions of the synthetic sodium carbonate manufacturing plants are attributed to this manufactured product.

5.3. Data sources and data quality

Synthetic sodium carbonate

Representative data have been used, based on ESAPA (European Soda Ash Producer Association) and European Commission documents. Indeed, the sodium carbonate process operated by European producers (synthetic process) is described by ESAPA in a specific Best Practice Reference Document (BREF) [1]. The European Commission issued a Reference Document on Best Available Technologies for the manufacture of Large Volume Inorganic Chemicals [2], with a section dedicated to sodium carbonate manufacturing essentially based on the ESAPA document. These two reference documents are used in the present study to describe the process for synthetic sodium carbonate in Europe. The process descriptions are sufficiently detailed to provide relevant CO_2 emissions.

From those data, the following CO_2 footprint (cradle-to-gate) can readily be calculated for the production of 1 kg of dense synthetic sodium carbonate:

From fossil fuels:	1.06 +/- 0.23 kg CO_2 eq. / kg synthetic sodium carbonate
From electricity:	0.04 +/- 0.02 kg CO_2 eq. / kg synthetic sodium carbonate
From raw materials:	0.06 +/- 0.02 kg CO_2 eq. / kg synthetic sodium carbonate
Total:	1.16 +/- 0.27 kg CO_2 eq. / kg synthetic sodium carbonate

Remark on Solvay's operations:

Solvay's operations represent a significant part of the manufacturing of sodium carbonate in Europe. Therefore the references used are also representative of Solvay's process. To be noted that a more detailed analysis, internal to Solvay, based on data of Solvay's operations in Europe and stemming from an exhaustive inventory of inputs and outputs of actual processes leads to a similar value for carbon footprint.

Glass manufacture

The production of glass has been thoroughly analysed by AGC Glass Europe, based on internal primary data from the company's operations. From that analysis, the carbon footprint (from cradle-to-gate) was calculated for the production of two types of glazing:

- Single glazing, uncoated, 4 mm thick
- Double glazing, low-e, 4 – 16 – 4 (4 mm glass, 16 mm space containing 90% Argon + 10% dry air, 4 mm glass).

The data calculated by AGC Glass Europe and used here have been calculated in conformity with EN 15804 and submitted to critical reviews (See AGC Glass Europe EPD's for float glass (Planibel) and for double glazing units (Thermobel)).

Glazing use stage

Energy consumptions: to determine energy consumption in each considered European zone (figure 3), the computation tool CAPSOL (http://www.physibel.be/) was used (source: AGC Glass Europe [3]).

This software allows a precise and complex computation of the overall energy exchanges between the inside and the outside of the considered model house, considering an entire set of characteristics. It is based on specific data for outside temperature distribution as well as energy mix for residential building heating in each zone.

Remark on conversion of energy consumptions to GHG emissions: Due to the use of public data such as the ESAPA study and the CAPSOL software, it was not possible to strictly use the latest IPCC 2013 100y set of GWP, as recommended. The results presented here are thus based on IPCC 2007 100y set of GWP. However, because the small difference between those two sets and the fact that CO_2 itself is by far the most important contributor to the carbon footprints reported here, it can be assumed that IPCC 2007 100y gives a consistent and relevant set of GWP.

Summary of data sources

The above-table (Table 2) gives a summary of the data sources used.

Quality of sources

Data for both synthetic sodium carbonate production and glass production present high levels of relevance and completeness. They describe, based on primary data collected by the industrial companies concerned (alone for glass or in a consortium for synthetic sodium carbonate), large processes, which have been operated for a long time with a slow kinetics for changes, as they have been optimized all along their lifetime. Even though data for synthetic sodium carbonate are older than 10 years, they are still representative of the present situation, and can in any case be considered as conservative.

Data for synthetic sodium carbonate relate to European manufacturing operations, in line with the scope of the study. Synthetic sodium carbonate used for glass for glazing in Europe mainly comes from European manufacturing sites because of transportation costs. Consistency between the two compared solutions is not a question since the same material is used in both solutions, only the involved quantity changes.

Data have been subject to critical reviews conducted on both the ESAPA's study for synthetic sodium carbonate and the AGC Glass Europe's study on glass.

Accuracy for those data for material production can certainly be improved; however, considering the very low contribution of those steps of the glass life cycle, it is fully consistent with the purpose of the present study.

Concerning the use stage, the CAPSOL software provides a high level of quality and completeness, with modelling of the entire buildings. So, only a small part of its outputs are used within the boundaries of the present study (heat loss through a surface of glazing for which the coefficient of heat transfer is accurately known). The use of differentiated data for 7 different climate and geographic zones in Europe also improves the level of accuracy and relevance for outside temperature profiles and energy mixes.

TABLE 2 - SUMMARY OF THE SOURCES OF DATA USED IN THIS STUDY

life cycle step	source of data	data quality
soda ash production	ESAPA study (2004)	high level of quality, conservative approach as process improvements might have occured since that publication.
glass production	AGC Glass europe internal study	high quality study, based on primary data and peer reviewed
window installation	not included	
use stage	computation	high quality, based on sophisticated models, approved by the building sector in Europe
end-of-life	not included	

5.4. Calculations of avoided emissions

Glazing production

Based on the hypotheses and methodological choices presented above, the results for carbon footprint of glazing production are given in table 3.

TABLE 3 - CARBON FOOTPRINT OF GLAZING ELEMENT MANUFACTURE

For 1 m² of glazing	Single Glazing 4 mm	Double Glazing 4mm - 16mm (90% Argon) - 4mm
Carbon footprint (from cradle-to-gate)	12 kg CO_2 eq.	32 kg CO_2 eq.
O/w contribution of synthetic sodium carbonate production	2,4 kg CO_2 eq.	4,8 kg CO_2 eq.
	20%	15%

Energy losses via glazing

Based on the temperature profile in each zone, CAPSOL computation returns the following energy losses during 1 year through 1 m² of glazing in each European zone (see table 4) for:

- Single glazing, uncoated, 4 mm thick (SGU U-value = 5.7 W/(m².K)
- Double glazing, low -e coated, 4 – 16 – 4 (4 mm glass, 16 mm space containing 90% Argon + 10% dry air, 4 mm glass) (DGU U-value = 1.1 W/(m².K)

TABLE 4 - ENERGY LOSSES DURING 1 YEAR THROUGH 1 M² OF GLAZING (SGU = SINGLE GLAZING / DGU = DOUBLE GLAZING)

kWh/m².year	Model	City	SGU U-value = 5,7	DGU U-value = 1,1
CENTRAL MARITIME	average	Brussels	432	93
SOUTH CENTRAL	average	Sofia	419	76
NORTH	average	Helsinki	648	149
CENTRAL	average	Praha	490	102
SOUTH	average	Rome	164	15
CENTRAL CONTINENTAL	average	Frankfurt	409	84

Energy mix

The energy mix for residential building heating differs between zones, as well as the electricity mix (how electricity is generated in each zone). Those differences result in different carbon footprints (see table 5) for 1 kWh consumed in order to compensate for energy losses through the glazing.

TABLE 5 - GHG EMISSIONS PER KWH. CO_2 EMISSION FACTOR CALCULATED FROM THE ENERGY MIX FOR RESIDENTIAL BUILDING HEATING. SOURCES: EUROSTAT AND EUROPEAN LIFE CYCLE DATABASE

Climate Zone	CO_2 emission factor (kg CO_2 / kWh)
CENTRAL MARITIME	0.303
SOUTH CENTRAL	0.378
NORTH	0.298
CENTRAL	0.347
SOUTH	0.345
CENTRAL CONTINENTAL	0.369

GHG emissions

Combining table 3 and table 4, GHG emissions due to energy losses through 1 m² of glazing during 1 year can be computed (table 5) in each zone for the two types of glazing.

TABLE 6 - GHG EMISSIONS TO COMPENSATE ENERGY LOSSES THROUGH 1 M² OF GLAZING DURING 1 YEAR

Kg CO_2 /m².year	SGU U-value = 5,7	DGU U-value = 1,1
CENTRAL MARITIME	131	28
SOUTH CENTRAL	158	29
NORTH	193	45
CENTRAL	170	35
SOUTH	57	5
CENTRAL CONTINENTAL	151	31

Avoided emissions in the considered European zones

Considering the market distribution (confidential data), for future / potential renovation (replacement of single glazing by double glazing, coated or uncoated) in the considered European climate zones, the average value for avoided emissions enabled by such replacement can be calculated over the zones per m² of replaced glazing:

- Per year
- For the 30 years of the reference service life of the new double glazing
- Taking into account the emissions for the considered functional unit at the manufacturing stage (11 and 22 kg of glass respectively, see 5.4).

TABLE 7 - AVOIDED EMISSIONS ENABLED BY REPLACING SINGLE GLAZING BY DOUBLE GLAZING, PER M² OF GLAZING (EUROPE – AVERAGE FOR 7 ZONES) DURING ONE YEAR AND DURING THE ENTIRE SERVICE LIFE (RSL = 30 YEARS) – ROUNDED FIGURES

	Unit	SGU U-value = 5,7	DGU coated U-value = 1,1	Avoided emissions
European average	kg CO_2 / m².year	143	29	114
	kg CO_2 / m².RSL	4,296	863	3,434

6. Results

6.1. Avoided emissions

GHG emissions during the entire life cycle of both types of glazing are summarized in figure 4 and table 7, for 1 m² of glazing.

FIGURE 4 - COMPARISON OF THE GHG EMISSIONS FOR THE FABRICATION OF THE GLAZING UNITS WITH THAT LINKED TO THE HEATING OF THE HOUSES DURING THE ENTIRE LIFE CYCLE OF BOTH SOLUTIONS FOR GLAZING. THE FIGURE HIGHLIGHTS THE EMISSIONS AVOIDED DURING 30 YEARS WHEN SUBSTITUTING 1 M² OF SINGLE-GLAZED WINDOWS BY 1 M² OF LOW-E COATED DOUBLE-GLAZED WINDOWS IN EUROPEAN HOUSES.

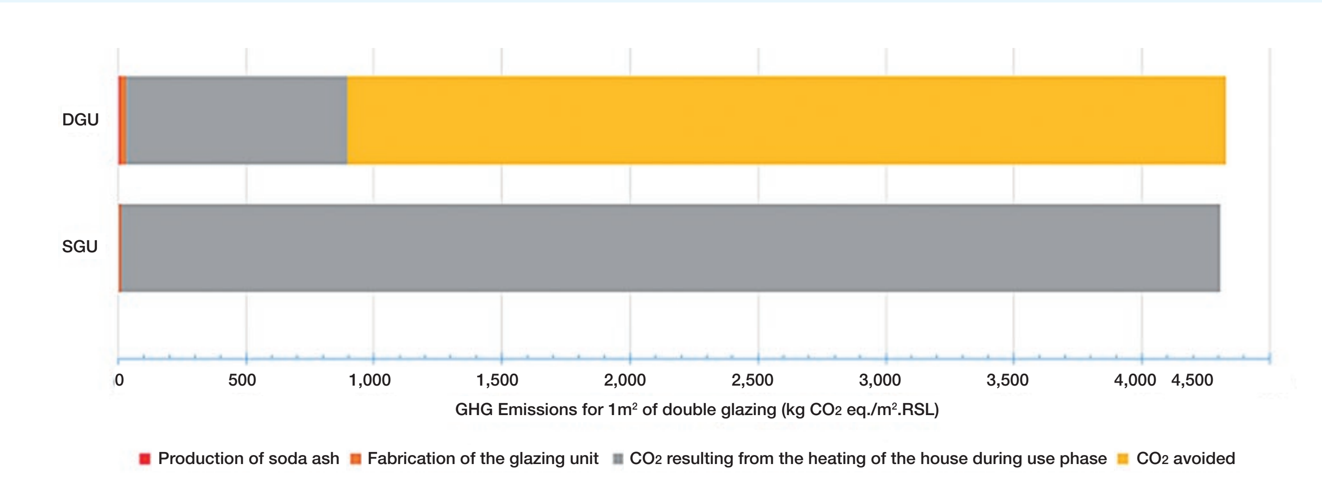


TABLE 8 - GHG EMISSIONS (KG CO_2 EQ.) FOR 1 M2 OF GLAZING (ROUNDED FIGURES) OVER THE LIFE CYCLE

	GHG emissions for 1 m² of glazing (kg CO_2 /m²)	
	Solution to compare to: single glazing	Reporting company solution: double glazing
Synthetic sodium carbonate production	2.4	4.8
Glazing production (excluding synthetic sodium carbonate production)	9.6	27.2
Use stage (reference service lifetime of 30 years)	4 296	863
TOTAL (over the entire life cycle)	4308	895
Avoided emissions (difference)		3414

The GHG emissions for 1 m² of glazing are thus:

- 4,308 kg CO_2 eq. for a single glazing (4 mm thick; U value = 5.7 W/(m-².K))
- 895 kg CO_2 eq. for a low e double glazing (4 mm glass, 16 mm space containing 90% Argon + 10% dry air, 4 mm glass; U value = 1.1 W/(m-².K)),

leading to a difference in GHG emissions of 3,414 kg CO_2 eq. per m² of glazing over the reference service life of 30 years.

The CO_2 emitted for the heating of the house during the use stage is much larger than the CO_2 emitted during the entire life cycle of glazing: Glass production and – as a part of it - synthetic sodium carbonate production contributions to emissions are hardly visible on the bar graph.

Extrapolation to European market

With a consumption of 105 million square metres of new DGU in Europe (EU 28, Eurostat, 2015) (and the resulting production of 439,000 tonnes of synthetic sodium carbonate) for the European market of glazing replacement (replacement of single glazing by double glazing), the avoided emissions – attributable to the production of this year as an example, amount to 360 million tonnes of CO_2 eq. (over the 30 years of their expected lifetime).

6.2. Scenario analysis: Energy generation hypothesis

The emissions for the 2 compared solutions, and the resulting calculated avoided depend on the technology mix prevailing to generate the energy needed to heat the houses. Avoided emissions may decrease if for example a significant move takes place towards renewable energy for building heating in the future.

It is difficult to propose a sensitivity analysis based on such hypotheses since the mix that is presently used by the CAPSOL software is not readily available and that hypotheses for an alternative scenario would be complex, due to the fact that several climate zones (with specific policies for evolution towards renewable energy) are considered.

7. Contribution of sodium carbonate to the avoided emissions

Significance of contribution: "extensive"

It is important to qualify whether sodium carbonate plays a key role in the avoidance of GHG emissions. As an indispensable and key ingredient in the composition of glass, the contribution of sodium carbonate can be qualified as "extensive" (according to the definitions of the WBCSD Guidance: "The chemical product is part of the key component and its properties and functions are essential for enabling the GHG emission avoiding effect of the solution")

Quantified contribution

According to the WBCSD guidance, the avoided emissions should not be attributed in the first place to individual value chain partners, because they result from the combined contribution of all value chain actors. The overall avoided emissions are the key element to be considered. They represent in total, for 1 m² of glazing, 3,414 kg CO_2 eq. (a reduction from 4,308 kg CO_2 eq. to 895 kg CO_2 eq.).

However, estimating to what extent the different materials contribute to the avoided emissions can be done, according to the guidance, following 3 possible approaches (c.f. guidance recommendations):

- According to the respective mass involved in manufacturing the glazing,
- According to the respective costs of the materials,
- According to their functional contribution to thermal conductivity reduction.

Excluding the low-e coating

In order to exclude the contribution of the low-e coating, this contributions needs to be evaluated. Indeed, this coating in the double glazing significantly contributes to the total energy saving due to the double glazing. Low-e glass is specially treated with a microscopically thin, virtually invisible transparent coating on one surface. The coating reflects heat back into the building, thereby reducing the heat loss through the window. It also reduces the heat transfer from the warm (inner) pane of glass to the cooler (outer) pane, thus further lowering the amount of heat that escapes from the window. The coating allows large amounts of solar energy to enter the building, thereby heating it [4]. The properties of Low-E coating enable the insulating glazing to reach a U-value of 1.1 where in the absence of low-e coating a double glazing unit will only reach a U-value of 2.5. This contribution depends on the meteorological conditions in the considered climate zone. From the table below (table 9), it can be concluded that on average the CO_2 avoided thanks to the coating amounts to 32% of the total (Average at European level).

FIGURE 5 - DOUBLE GLAZING UNIT WITH ONE LOW-E COATING (SOURCE: GLASS FOR EUROPE)

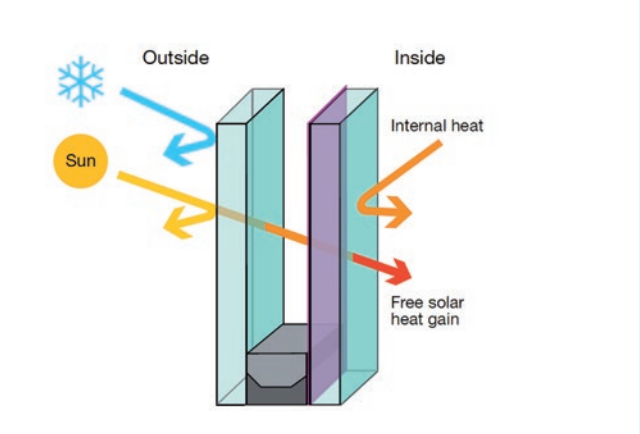


TABLE 9 - ENERGY SAVING EFFECT OF THE COATING (SOURCE: ASAHI GLASS EUROPE)

Energy Reduction due to the coating	Model	kWh/m^2.year	Proportion of total savings
CENTRAL MARITIME	average	113	33%
SOUTH CENTRAL	average	111	32%
NORTH	average	165	33%
CENTRAL	average	126	32%
SOUTH	average	37	25%
CENTRAL CONTINENTAL	average	107	33%

Avoided emissions excluding the effect of the coating: Thus, the avoided CO_2 emissions that can be attributed to the other elements of the double glazing, excluding the effect of the coating, amounts to 3,414 x (1-0.32) = 2,322 kg CO_2 eq.

Quantified contribution of sodium carbonate after excluding the role of the low-e coating: The mass allocation has been selected for this study. A calculation based on cost contribution was not possible due to the confidentiality issues related to costs. On the other hand, assessing the functional contribution to thermal conductivity of every of the other materials of the glazing is not achievable: the thermal conductivity results from the overall window systems, with no possibility to quantify the individual contribution of the various materials, which only together determine the conductivity. Moreover, the raw materials of the glass itself, for the same kind of reason, cannot be considered separately.

Table 9 presents a very simplified bill of materials (excluding the spacers) for one element of each type.

TABLE 10 - SIMPLIFIED BILL OF MATERIAL (EXCLUDING THE SPACERS AND CONSIDERING ATMOSPHERIC PRESSURE OF PURE ARGON BETWEEN THE TWO GLASS PLATES OF THE DOUBLE-GLAZED ELEMENT)

for 1 m^2 of glazing (kg)	single glazing		double glazing	
synthetic sodium carbonate	2.09	19%	4.18	19%
sand	6.82	62%	13.64	62%
other	2.09	19%	4.18	19%
argon	0.0	0	0.03	0.14%
total	11.0	100%	22.03	100%

Assuming a calculation based on mass contribution, synthetic sodium carbonate can be estimated to contribute to close to 19%.

Thus, with a contribution taken at 19% of the above calculated 2,322 kg CO_2 eq. avoided emissions, 441 kg CO_2 eq. can be attributed to the 4.18 kg of sodium carbonate needed to produce 1 m^2 of double glazing 4-16-4. This represents 106 kg CO_2 eq. avoided emissions per kg of sodium carbonate.

This also means that for every kg of CO_2 emitted during the manufacturing stage of sodium carbonate (1.16 kg CO_2 eq. / kg of sodium carbonate), 90 kg CO_2 eq avoided on the overall life cycle can be attributed to this raw material.

8. Review of results

ESAPA's study for synthetic sodium carbonate production is a reference document, approved and validated by CEFIC; and AGC Glass Europe's study for glass production has been peer-reviewed. Quantis has reviewed the compliance of the study with the WBCSD/ ICCA guidance on avoided emissions).

9. Study limitations and future recommendations

The study focusses on renovation in Europe. A limitation stands in the evolution of energy mix for residential building heating. The potential growing contribution of renewable energy may affect the estimated avoided emissions.

10. Conclusions

Overall avoided emissions

This study quantifies the GHG emissions that may be further avoided thanks to the replacement of existing single glazing with double glazing windows (and the resulting energy savings), in residential buildings in Europe.

Although actual renovation in fact consists in the replacement of single glazing by coated (metallic oxides) double glazing, this study however focusses on the role of glass and of sodium carbonate in avoided emissions, and the final results excludes the benefit of the coating from the scope.

The insulating effect of double glazing as compared to single glazing stems from a drastic reduction of the thermal losses through windows. Estimated avoided emissions, considering the entire life cycle of double glazing compared to single glazing, amount to 3,400 kg CO_2 eq. per m^2 of double glazing over a 30 year reference service lifetime. Extrapolation to the considered European market gives a figure of 360 million tonnes CO_2 avoided emissions for a single year of replacement of windows (Based on DGU consumed in EU28 in 2015. Eurostat).

Because these avoided emissions result from the combined contribution of all value chain actors (raw materials manufacturers, glass manufacturers, window manufacturers… down to the house inhabitants themselves), they belong to all value chain actors.

Estimate of the contribution of sodium carbonate
The contribution of sodium carbonate is "extensive" according to the WBCSD guidance and it is possible to estimate it, assuming a mass allocation, at 19% of the 2,322 kg avoided emissions directly due to the double glazing system (excluding the effect of the low-e coating). This represents 90 kg CO_2 eq. avoided for every kg of CO_2 eq emitted during sodium carbonate manufacture for the window renovation market in Europe. To be noted that possible variations between different sodium carbonate manufacturing sites in terms of CO_2 efficiency would not impact the overall avoided emissions estimation, as the use stage of windows represents by far the highest contribution, and the relative contributions of glass manufacturing and – as a part of it – synthetic sodium carbonate production are very small.

Sensitivity to renewable energy ratio
Overall calculated avoided emissions would of course be affected if the ratio of renewable (low carbon) energy in the European mix for residential building heating would significantly increase in the coming 30 years.

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Case 17 100% Bio Based Polyethylene Terephthalate (PET)

Toray Industries, Inc.

COMMISSIONER AND PERFORMER OF THE STUDY

The study was commissioned by Toray Industries, Inc., performed by Toshiro Senba, Iida Women's Junior College and Dr. Atsushi Inaba, Kogakuin University and reviewed by Quantis.

1. Purpose of the study

The objective of the study is to calculate the GHG emission of the 100% bio based PET which is the material of polyester textile products, in comparison with the alternative, petroleum based PET.

PET is made from two materials which are chemical products previously from petroleum refinery.

100% bio based PET, the chemical product the study focuses on, is a newly developed material made from TPA and ethylene glycols (EG), both of which are derived from bio based raw materials instead of petroleum based ones. Material-derived carbon emissions by incineration of 100% bio based PET on disposal stage are considered to be zero since the resource plants absorb the same quantity of carbon from air for photosynthesis when growing.

Polyester filaments and fibers from the resin are applicable to various products and applications, and life cycle carbon emissions of each product vary separately by the finished product and application. The reason we do not select a kind of textile product but its material to assess is to apply broadly the study result of the environmental impact to variety of textile products which are based on this PET resin.

The category of comparison is the category 3 (Product/technology comparison within the same sector.)

2. Solutions to compare

2.1. Description of the solutions to compare

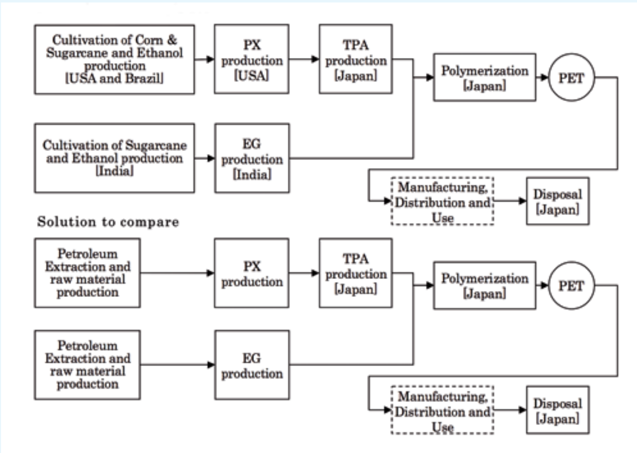
The study compared two alternative kinds of the PET resin which are the material of polyester textile products. The global mill consumption as demand of fibers in 2015 was about 88 million tonnes and 61% of it were synthetic fibers including the polyester. The fiber demand around 2020 is expected to be 100 million tonnes and more than 50% of it seems to be polyester fibers (reference (1)). The reporting company's solution can be applied to the material of these polyester fibers.

The reporting company's solution is the 100% bio based PET. PET (chemical formula is (C10H8O4)n) is a kind of polyester which is manufactured by polymerization with TPA (C8H6O4) and EG (C2H6O_2). Conventionally TPA and EG are chemical products from petroleum refinery. The bio derived TPA as a material of the 100% bio based PET is produced in Japan from the raw material para xylene (PX, C8H10) by Toray Industries, Inc. The PX in the study is assumed to be manufactured from ethanol, 80% of which is made from United States corn and 20% is from Brazil sugarcane by Virent Inc. technology. The bio derived EG as a material of the 100% bio based PET is produced in India from waste sugarcane molasses by India Glycols Ltd. Polymerization process with TPA and EG is in Japan.

The 100% bio based PET and the petroleum based PET can be manufactured by the same process facility of Toray. They have the identical physical properties and can be used for the same application, style and design of textile products.

The factor to affect the emissions through full life cycle is only the raw materials manufacturing stage, which is different between the alternatives.

CHART 1 - REPORTING COMPANY'S SOLUTION



3. Functional unit and reference flow

3.1. The function and the functional unit

The function of the solutions compares is to provide the plastic physical properties needed as a material of textile products by 100% of polyester. The functional unit has been set as to produce and to incinerate the 1 kg of PET.

3.2. Reference flow

The reference flow of both solutions is 1 kg of PET resin.

3.3. Quality requirements

The studied solutions provide the same function as the kind of resin because the physical properties of both are the identical, and thus textile products made from them have the identical performance such as processability and durability. The consumers of finished products do not distinguish between both.

3.4. Service life of the solution

The service life of textile finished products was not set in this study because the form and application of finished products vary so broadly. The length of service life of textile finished products does not affect the calculation and its results of GHG emissions.

3.5. Time and geographic reference of the study

The time related coverage of the data is from 2011 through 2016. The primary data of TPA production and PET polymerization were based on the most recent data available from 2015 to 2016, and references as secondary data were based on 2011 and 2013.

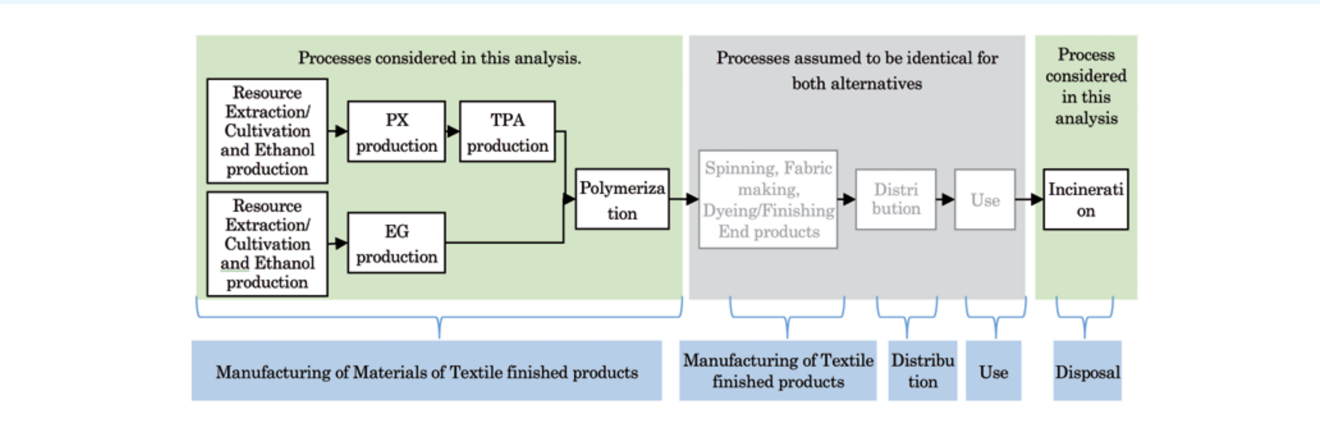
The geographical coverage is the United States, Brazil, India and Japan. The material production of the reported solution is based on the United States, Brazil, India and Japan, and polymerization is based on Japan (Chart 1.)

4. Boundary setting

The value chain of the finished product with the solutions is shown in Chart 2.

The study does not cover the following life cycle stages, and these are identical between both solutions; manu-facturing of the finished textile products, distribution and use stage.

CHART 2 - PRODUCT SYSTEMS



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 the 100% bio based PET and the petroleum based PET.

The characterization factors of the GHG were the global warming potential 100 years by IPCC 2007. The reason not to use the most recent version of IPCC but to employ IPCC 2007 is consistency with the existing study (reference (2)) on which the study based. Both of the base case and the future scenario were assessed by the same GWP factors.

5.2. Allocation

Mass allocation method between the product and coproducts was employed in the bio based PX process that the primary data was used.

In the calculation of the bio based EG production (reference (2)), the allocation based on the economic value was employed.

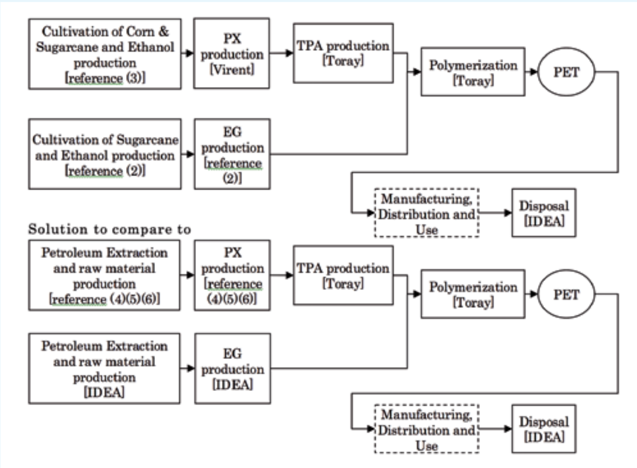
In the TPA production from PX, the steam as a utility is generated by heat from the oxidation, as well as the TPA. We did not employ the allocation but subtracted the impacts of the steam from the total process emissions.

5.3. Data, data sources and data quality

Data sources of each process are as in Chart 3. Virent Inc. and Toray Industries, Inc. provided primary data for the process of each.

As the life cycle inventory data, the inventory database IDEA (Inventory Database for Lifecycle Analysis developed by AIST and JEMAI) is prioritized and supplemented with the information in the references.

CHART 3 - DATA SOURCES - REPORTING COMPANY'S SOLUTION



5.4. Cut off

The catalyst used in the polymerization process, output of the bromomethane from the TPA production and the waste polymer out of the polymerization process are cut off as they are less than 0.5% by weight of the process output.

6. Results

6.1. Avoided emissions

The result of GHG emissions in each process of both solutions is shown in Table 1 and Chart 3.

In comparison to the solution to compare to, the reporting company's solution has higher emissions during the Resource through the TPA production, but it has 1.08 kgCO_2e/kg-PET of avoided emission as carbon emission from incineration at the Disposal stage is neutralized by carbon uptake in the material plants.

In the scope of the study, the Resource through TPA production process contributes more highly than others to GHG emissions, therefore the efficiency in the process is the key parameter. Primary factors in each process are the electricity and the steam inputted as the energy (Chart 4).

In the TPA production from PX, as shown in the second graph of Graph 2, the emissions from the steam was a negative quantity. This represents that the steam is generated by heat from the PX oxidation, and the emissions from general steam generation, which can be alternate the generated steam, were subtracted from the process emissions.

TABLE 1 - AVOIDED EMISSIONS PER 1 KG OF PET (KGCO_2E/KG-PET)

	a. Reporting company's solution	b. Solution to compare to
Resource through TPA production	2.39	1.04
Resource through EG production	0.37	0.50
Polymerization	0.67	0.67
End products, distribution and use stage	-	-
Disposal	0	2.29
Total	3.42	4.50
Avoided emissions (b-a)	1.08	

CHART 3 - GHG EMISSIONS OF REPORTING COMPANY'S SOLUTION AND SOLUTION TO COMPARE BY PROCESS (KGCO_2E/KG-PET)

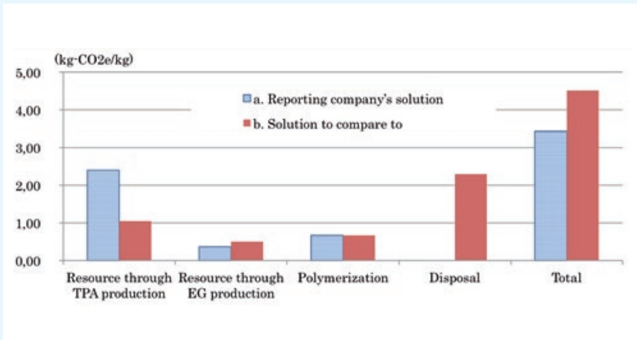
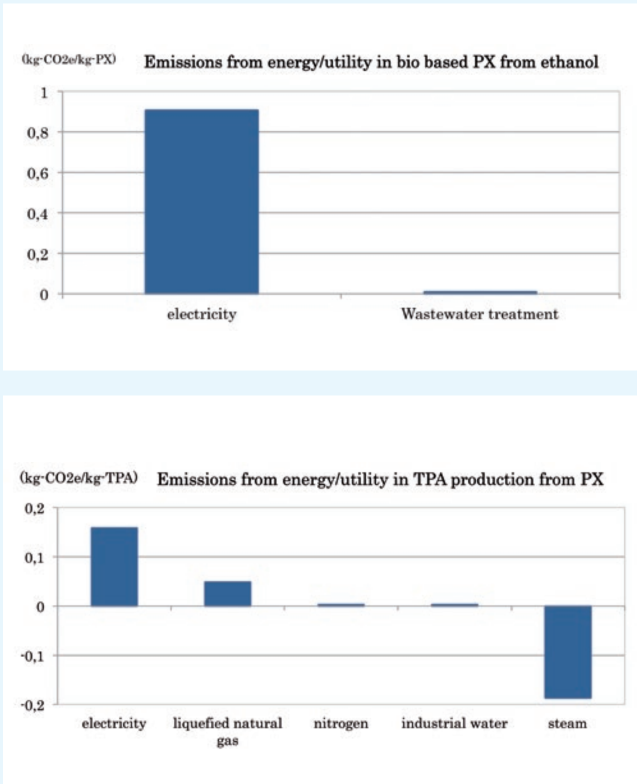
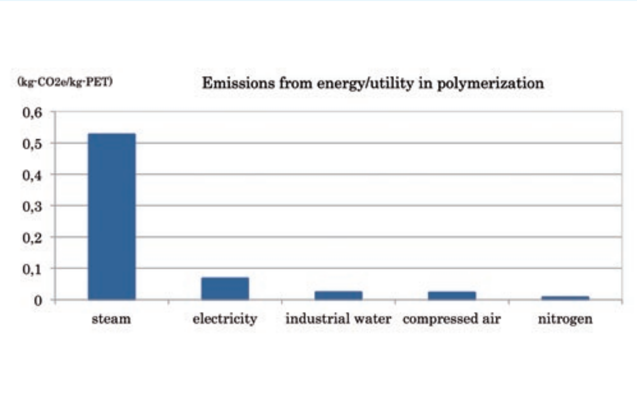


CHART 4 - GHG EMISSIONS FROM ENERGY/UTILITY IN EACH PROCESS





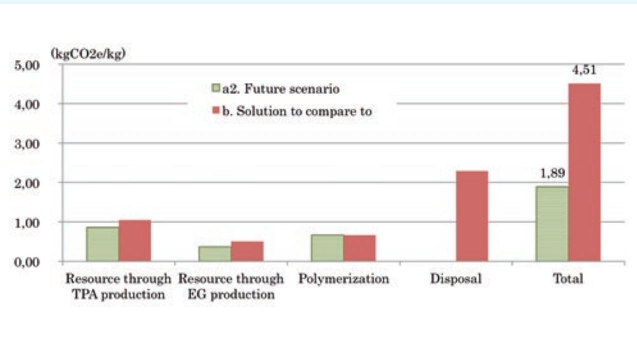
6.2. Scenario analysis

The base case evaluates the bio derived PX, the raw material of the 100% bio based PET, manufactured from ethanol, which is consisted 80% of US corn ethanol and 20% of Brazil sugarcane ethanol. As the future scenario, we assumed the case of 100% bio based PET from bio PX by 100% sugarcane ethanol.

TABLE 2 - AVOIDED EMISSIONS PER 1 KG OF PET IN FUTURE SCENARIO (KGCO$_2$E/KG-PET)

	a2. Future scenario (PX from ethanol 100% by sugarcane)	b. Solution to compare to
Resource through TPA production	0.85	1.04
Resource through EG production	0.37	0.50
Polymerization	0.67	0.67
Finished products, distribution and use stage	-	-
Disposal	0.00	2.29
Total	1.88	4.50
Avoided emissions (b-a)	2.62	

CHART 5 - GHG EMISSIONS OF SOLUTION IN FUTURE SCENARIO AND SOLUTION TO COMPARE BY PROCESS (KGCO$_2$E/KG-PET)



The prospect of the industry is as follows. The global mill consumption as demand of major fibers was about 88 million tonnes in 2015. The expected demand around 2020 is 100 million tonnes and the majority of it seems to be the polyester fibers (reference (1)).

Assuming that 10% of the polyester fiber demand in 2020, i.e. 5 million tonnes of polyester fibers, are replaced into 100% bio based PET in the base case instead of petroleum based PET, 5.4 million tonnes of GHG emissions can be avoided. If a half of the demand, 25 million tonnes of polyester fibers by 100% bio based PET are used, the avoided emissions can be estimated at 27 million tonnes.

6.3. Simplified assessment

Manufacturing of the finished textile products, distribution and use stage were not covered in the study as the life cycle stages are identical between both alternatives. The main reasons to employ the simplified calculation in the study are as follows:

1) polyester fiber/filament has large variety of products and application, and the variety changes the emissions through full life cycle, and
2) the study results can be applied to variety of value chain of our textile products as a basic study of the PET as a material.

The analysis limitation by omitting these identical stages is described below in [9. Study limitations and future recommendations]. The omitting emission does not change the overall conclusion of the study.

As some examples of the estimation of omitted emissions, the following references can be found. According to these references and the result of this study, the total GHG emissions during the spinning, fabric making (weaving/knitting), dyeing & finishing and manufacturing of textile finished products (sewing, etc.) can be estimated to be around 13 or 14 kg-CO$_2$e/kg-PET, and the emissions during use stage (cleaning or washing by consumers, etc.) can be estimated to be 10 to 30 kg-CO$_2$e /kg-PET.

- According to the detailed information of "Training shirt, jam up® jacket" registered in the CFP program (reference (7)), the cradle-to-gate carbon foot print of one jacket by 100% polyester (541 g) is calculated as 10.0 kg-CO$_2$e (8.1 kg-CO$_2$e in material stage and 1.9 kg-CO$_2$e in manufacturing stage), which can be 18.48 kg-CO$_2$e for 1 kg of polyester jacket. The emissions during use stage is 2.4 kg-CO$_2$e per jacket by 100 times of home cleaning (without ironing), which can be 4.4 kg-CO$_2$e for 1 kg of jacket.
- In the "Life Cycle Assessment Report of Textile products (clothing)" (reference (8)), the cradle-to-gate CO$_2$ emissions of one tonne of polyester blouse (total 143 g/item; polyester fabric 121 g and other parts 22 g) is calculated as 5'507 kg-C. When allocating the environmental impacts between the polyester fabric and other parts, the emissions are 17.1 kg-CO$_2$/kg-PET fabric.
- According to the reference "An Investigation into Differences in Method of Drying Domestic Laundry Based on Area Survey" (reference (9)), the GHG

emissions by one time of washing one dress shirt (250 g) is calculated to be around 0.098 through 0.169 kg-CO_2e/shirt by household washing (washing, ironing and machine drying) and to be 0.296 kg-CO_2e/shirt by laundry washing by commercial cleaning service (washing by drum type washing machine with hot water and press).

7. Significance of contribution

The 100% bio based PET as the reporting company's solution is main material of the polyester textile products and contributes fundamentally to the reduction of the textile finished products.

The plant derived solution and the petroleum derived solution to compare have the identical physical properties as the material. Therefore employing the bio based raw materials leads the avoided emissions through full life cycle of the finished products without changing any quality and functionality.

With carbon absorption by the material plants, the reporting company's solution neutralizes the carbon emissions during the disposal stage. Toray as a chemical supplier contributes the avoided emissions by providing the textile products made of the bio based PET, and the effort of the avoidance is attributed not only to the chemical industry but the value chain partners of full life cycle of the finished products.

8. Review of results

Any critical review was not carried out for the study. The experts in the Japan Chemical Industry Association and the ICCA had reviewed the study report in accordance with the requirements of the new ICCA guidelines. The major review comments were on the absence of viewpoints to be added to the scenario analysis and the study limitations.

9. Study limitations and future recommendations

The results of the study show the avoided emission of the polyester resin which is a material of textile finished products. The finished products from the solutions are out of scope in the study and their properties (e.g. application, product type, design etc.) change emissions through the full life cycle. Following examples are the variation of emissions through the full life cycle by finished products application/type/design.

- During the production stage of the finished textile products, selection of fuels for the heat sources, selection and quantity of dyestuff and agents to be used, existence of finishing for functionality and efficiency of each process are change the emissions through the full life cycle.
- During the use stage of the finished textile products, the service life of the finished products (the length of time the products are used), the existence of cleaning, the frequency of cleaning and the way of cleaning affect the emissions through the full life cycle.

When the new production technology of bio based materials (TPA and EG) is further developed and also the processes and energy efficiencies are further improved, the GHG emissions can differ from the result of the study. In such cases, the result of this study may not be applicable.

Land use change

Concerning the possible impact from the land use change, we additionally estimated the land area of agricultural use for sugarcane and corn, which can be used for the bio based materials, because the trade-off between GHG emissions and land use may occur in the comparison between the bio based materials and the petro based materials.

The land area used for TPA production can be calculated from the sugarcane and corn yield per year per unit area. The sugarcane yield per year per hectare in Brazil is 75 tonnes and the ethanol yield per kg of sugarcane is 0.072kg (reference (3)). The corn yield per year per hectare in USA is 9.92 tonnes, and the ethanol yield per kg of corn is 0.33kg (reference (3)).

As for EG, the sugarcane molasses yield per year per hectare in India is assumed to be 2.22 tonnes (reference (10)). Since the information of sugarcane cultivation in India is not available in the reference (2), the land use of sugarcane production for EG is assumed based on other reference available (reference 10).

Based on the estimations mentioned above, 15.1 m^2 of crop land would be used in a year to product bio based feedstocks per kg of PET in the base case, and 13.2 m^2 of crop land would be used in the future scenario.

It is also recognized that other trade-off such as biodiversity and water consumption may also occur in the production of the feedstock for bio based materials, though such trade-offs were not assessed in this study due to lack of relevant information.

The reporting company's solution may have more impacts due to the potential trade-offs mentioned above than the solution to compare.

10. Conclusions

The reporting company's solution has 1.08 kgCO_2/kg-PET of avoided emissions, and the carbon uptake by material plants contributes the avoided emissions. Since the carbon in the TPA composes 80% of carbon in the PET, the effort to reduce emissions during the production of TPA and its raw materials provides the major influence. There is great variety of products and application of textile made from the reporting company's solution, and application and usage of the finished products varies emissions during out of scope of the study and during full life cycle as well.

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WBCSD & ICCA guidance version 1 and 2

The guidelines (Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies) were developed with the aim of increasing the consistency and credibility of avoided emissions estimates communicated by chemical companies about their products. The guidelines were developed by the chemical sector task force of World Business Council for Sustainable Development (WBCSD) and the International Council of Chemical Associations (ICCA). A first version was published in October 2013. Following a first series of case studies, the guidelines have been slightly improved to better meet the practitionners needs. Published in 2017, Version 2 encompassed a number of improvements, including:

- The concept of value chain level is no longer limited to only chemical product or end-use level. The comparison can be made at the chemical product level, at the end use level or at any level in between
- The criteria to select the solution to compare to has been made less rigid than in version 1
- The concept of functionality has been added in the attribution approach

Version 2 is robust and stabilized

The ICCA/WBCSD guidance, after its 2017 revision, demonstrates that it is robust and stabilized. 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. For example, 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).

Data quality

Data quality is an important aspect when comparing two solutions. For example, when the data used for one of the compared solution are less representative, it reduces the confidence in the final results. 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. A number of case studies supplied by companies did not sufficiently address data quality or only addressed it at a high aggregation level.

Acknowledge-ments

The case studies in this report were offered by ten companies and two associations. ICCA would like to thank the people that have been involved in the avoided GHG emissions case studies project, in particular the ICCA Energy and Climate Change Leadership Group / cLCA Task Force Co-chairs: Michel Bande (Solvay), Motozo Yoshikiyo (Japan Chemical Industry Association) (2nd phase), and the cLCA Task Force Participants: Yuki Hamilton O. Kabe (Braskem S.A.); Michael H. Mazor (The Dow Chemical Company); Barclay Satterfield, Jason Pierce and Lauren Johnson (Eastman Chemical Company); Abdelhadi Sahnoune (ExxonMobil Chemical Company); Rob van der Heijden (Shell Global Solutions International B.V.); Pierre Coërs (Solvay); Hiroyuki Kamata (Toray Industries, Inc.); Kiyoshi Kasai and Reiko Nonaka (Japan Chemical Industry Association).

ICCA would also like to thank the other people who have been involved in the development of the case studies, and in particular: Klas Hallberg (Akzo Nobel), Nicola Paczkowski (BASF), Yuki Hamilton Onda Kabe (Braskem), Christina Merz (Evonik), Randy Waymire and Jason Pierce (Eastman Chemical Company), Rakesh Bhartia (India Glycols), Makoto Terauch (Japan Chemical Industry Association), Rajesh Mehta and Ananda Sekar (SABIC), Jean-François Viot (Solvay) and Guy Van Marcke (AGC Glass Europe), Jiro Mori (Sumitomo Chemical).

Ecofys has reviewed the first series of cLCA case studies that were published on the ICCA website in December 2015, while Quantis has reviewed a second series of case studies in 2016, to check if they are in compliance with the ICCA & WBCSD guidelines "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 and Sebastien Humbert from Quantis for their review of the case studies and advice on their quality.

We would also like to thank Pierre Coërs (Solvay) in his role as Chair of the cLCA Task Force (3rd phase) for coordinating the case study project, and Nonaka Reiko for her active support.

Disclaimer for Case Studies

These case studies illustrate how the reduction of Greenhouse Gas Emissions can be enabled by chemical products: Chemical industry members offered life cycle assessment [LCA] case studies for the purpose of showing illustrative examples on how to calculate avoided greenhouse gas (GHG) emissions. The avoided emission calculations were based on the guidelines developed by ICCA and WBSCD (World Business Council for Sustainable Development) – Chemical Sector, with the support of Arthur D. Little and Ecofys. Other life cycle environmental impacts such as water and land use change were outside the scope and usually not considered.

INTERNATIONAL COUNCIL OF CHEMICAL ASSOCIATIONS

About the International Council of Chemical Associations (ICCA)

The International Council of Chemical Associations (ICCA) is the worldwide voice of the chemical industry, representing chemical manufacturers and producers all over the world. Responding to the need for a global presence, ICCA was created in 1989 to coordinate the work of chemical companies and associations on issues and programs of international interest. It comprises trade associations representing companies involved in all aspects of the chemical industry.

ICCA is a chemical industry sector with a turnover of more than 3,600 billion euros. ICCA members (incl. observers & Responsible Care members) account for more than 90 percent of global chemical sales.

ICCA promotes and co-ordinates Responsible Care® and other voluntary chemical industry initiatives. ICCA has a central role in the exchange of information within the international industry, and in the development of position statements on matters of policy. It is also the main channel of communication between the industry and various international organizations that are concerned with health, environment and trade-related issues, including the United Nations Environment Programme (UNEP), the World Trade Organization (WTO) and the Organisation for Economic Co-operation & Development (OECD).

ICCA operates by coordinating the work of member associations and their member companies, through the exchange of information and the development of common positions on policy issues of international significance. Three main issues focused on by ICCA are: Chemicals Policy & Health, Climate Change & Energy, Responsible Care®.

ICCA also serves as the main channel of communication between the industry and various international entities, such as inter-governmental organizations (IGOs) and NGOs that are concerned with these global issues.

www.icca-chem.org

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