ICCA-WBCSD Avoided Emissions Guidance Case Study

Materials for Light Weight Automotive Front End Module (FEM) Structural Applications, SABIC

1. Purpose of Study

This study was commissioned by SABIC and was completed in-house by the internal LCA team (Dr. Anju Baroth.) The objective of this study is to assess the life cycle environmental performance and quantify potential avoided GHG emissions of STAMAX^{TM} resin based FEM and PA-Steel hybrid FEM solutions.

2. Level in the value chain

The scope of the study is at the product end-use level in a large size passenger car where the STAMAX resin based FEM serves the purpose of light-weighting by replacing heavier FEM made with PA-steel hybrid material. This assessment consists of ***'Cradle-to-Grave'*** for both the solutions including material manufacturing (extraction and preparation), part production (fabrication), use phase (operation of a car and light weight benefits) and end of life (dismantling, separation, recycling, energy recovery and/or landfill). This approach will allow holistic assessment of impacts of products across life cycle.

3. Solutions to compare

The study compares a long glass fiber reinforced thermoplastic polypropylene (PP) used in an automotive front-end module (FEM) with a polyamide (PA)-steel hybrid FEM. Table 1 provides the typical average material composition for a 3.5 kg STAMAX FEM (30% market share as per 2012[1] data) and 6.07 kg PA-Steel hybrid FEM (25% market share as per 2012 data) respectively. The difference between inputs and outputs is the production scrap, which is sent to a recycler.

Table 1: FEM Material Composition

Material	Part	Input (Kg)	Output (kg)	Scrap (%)
STAMAX Resin	***STAMAX FEM***	***3.57***	***3.5***	***2%***
Steel parts	Upper beam	1.84	1.43	22.2%
	Lock part	0.51	0.40	22.2%
	Left vertical beam	0.99	0.77	22.2%
	Right vertical beam	0.99	0.77	22.2%
PA6-SG30*	Outer cover	2.75	2.7	2%
TOTAL PA-Steel Material	***Hybrid FEM***	***7.09***	***6.07***	

4. Functional unit

4.1. Function of the product/application and quality requirements

Light-weighting of automobiles using a combination of lighter thermoplastic composites and part design/optimization are the key strategies to achieve lower greenhouse gas (GHG) emission and fuel economy improvement targets. Automotive Front-end module (FEM) is a key structural component providing support and safety in the event of a collision, in addition to functional features such as air

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STAMAX^{TM} – Trademark of SABIC

* Polyamide 6 with 30% short glass fiber

cooling, heating, lighting, exterior styling and aesthetics. Conventionally, FEM's are made with steel or metal-plastic hybrid materials. However, long glass fiber reinforced thermoplastic Polypropylene (PP) solution offers light weight and meets all performance requirements. In this material solution, glass fiber provides the necessary modulus and the PP matrix gives required ductility. Figure 1 shows an integrated thermoplastic STAMAX resin based FEM.

Figure 1: STAMAX Front End Module

4.2. Service life

This study compares a FEM made from STAMAX resin with one made using PA-steel hybrid material. The functional unit is chosen as a “front body frame meeting all the quality and performance features of the FEM system over a life time of 200, 000 kms[2]”. The car model selected for this study is the Audi A4 (weight 1555 Kg, mileage 4.5 l/100 km).

4.3. Time and geographic reference

The geographical resolution and coverage of this LCA study is applicable to Europe. This study should remain relevant for at least 5 years. STAMAX resin production data used for this study is from 2011-2012. Additional data necessary to model material production and energy use were obtained from the Ecoinvent Databases v2.0 and are representative of years 2002 to present. Sensitivity analysis was done to cover the North American region to cover global applicability.

4.4. System Boundary

Figure 2 shows a high level flow diagram for the system boundary for the two product systems.

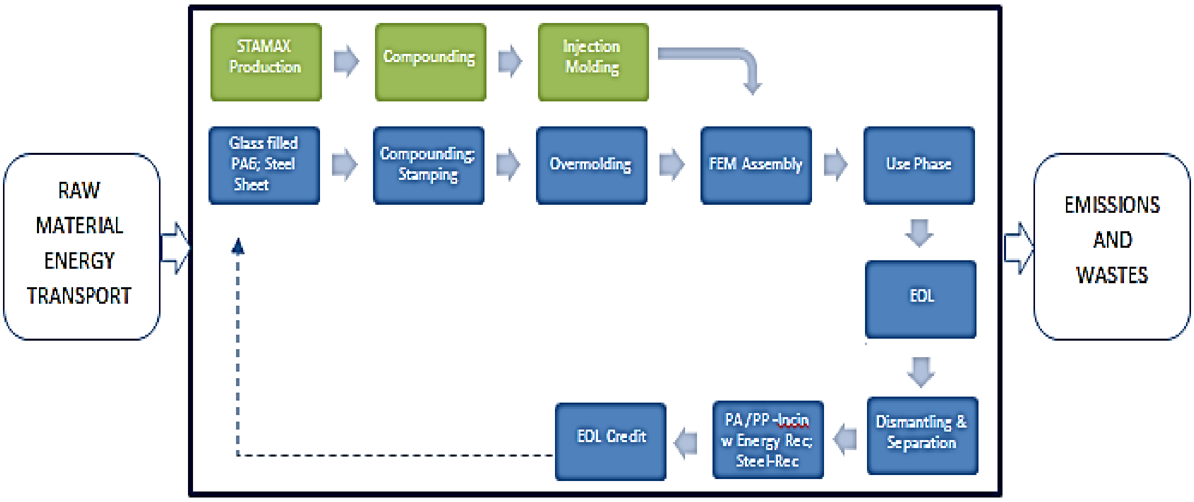

Figure 2: End-use level system Boundary for Front End Module

This study includes all the relevant upstream processes for production of materials, parts, use and end of life. Accordingly, the study boundaries of this LCI include and exclude the following elements:

Included	Excluded
• Upstream raw material production • Production and use of fuels, electricity and heat • Mechanical part production • Transportation of all raw materials • Use • End-of-life – Dismantling, separation, recycling, energy recovery and landfill	• Capital equipment and maintenance • Overhead (heating, lighting) of • manufacturing facilities if separable • Part assembly • Distribution to regional distribution sites • In-plant transportation • Service (repair and replacement) • Human labor

5. Life Cycle Inventory and Calculation Methodology

The data for manufacturing STAMAX compound was collected from recent SABIC plant data. Average European Ecoinvent datasets for PP and glass fiber were used. Part production is modeled using the European Ecoinvent dataset for injection molding, and adjusted to account for the reported scrap amounts in Table 1. End of life disposal option for STAMAX FEM is assumed as incineration and landfill in a ratio of 50:50. The disposal scenario is modeled using the average landfill and incineration Ecoinvent models available in SimaPro. Using the avoided burden approach, the benefit of recovered energy from incineration was credited to the STAMAX resin based FEM life cycle. The value is calculated based on the calorific value of mixed plastic waste[†] [3].

For the PA part of PA-Steel hybrid FEM, average European Ecoinvent datasets were used for Nylon 6, and glass fiber including average compounding and injection molding datasets. For steel component, The LCI dataset for galvanized, hot rolled coil was procured from Worldsteel Association (worldsteel). The data was obtained in 2012 and is representative of the galvanized hot rolled steel used in the manufacturing of the FEM beam components[4]. Since the recycling credit (91% recycled) is already included in the cradle to gate data provided by worldsteel, further credits were not included in the end of life models, to avoid double counting. For sheet fabrication, inputs required for the stamping process are calculated as per the material flow given in Table 1. End of life fate for PA portion is similar to STAMAX™ FEM (50 land fill: 50 Incineration with energy recovery).

For end of life, Ecoinvent datasets for processing of scrap steel have been used and represent a European recycling scenario. Dismantling, shredding and separation losses were considered for the complete FEM assembly at the end of life[5].

Transportation was included for different phases for both products, wherever available. All the background data were selected from the latest Ecoinvent Dataset available in the SimaPro software.

5.1. Calculation methodology

For the use phase, fuel savings due to lightweight design over the assumed vehicle lifetime mileage of 200, 000 km is calculated based on the NEDC (New European Driving Cycle) and the differential

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[†] Approximate Heating Value of Common Fuels, Michigan State University, http://www.hrt.msu.edu/energy/pdf/heating%20value%20of%20common%20fuels.pdf, 2004

efficiency of diesel engines. This study will use the principal as described in Koffler et al. (2010)^{5} to calculate the mass induced fuel consumption of each component (STAMAX resin based FEM and PA hybrid based FEM) using Fuel Reduction Value or FRV with power train adaptation (0.28 l/100kg/100km) as the base case. Fuel savings due to lightweight design is calculated by taking a difference in fuel consumption between two parts. Further, a sensitivity assessment is done for a scenario using FRV without powertrain adaptation (0.12 l/100kg/100km) to represent the possible difference in fuel savings. This study considers a vehicle lifetime mileage of 200, 000 km based on te EUCAR recommendation for large cars (Ridge, 1998). The methodology used in the study is shown below:

$Mref \ * V100kg * 0.01 = FCref$……………. (1)
$Maltcomp * V100kg * 0.01 = FCalt$……… (2)
$\Delta FR = FCref - FCalt$……………………………. (3)

Where, Mref = Mass reference component; Malt com= Mass alternative component; V100kg = Fuel Reduction Value (NEDC) = 0.28l/100km/100kg; FCref = Fuel Consumption of ref comp; FCalt = Fuel Consumption alt comp; ΔFR *= Reduction in Fuel consumption*

It should be noted that this study focuses on a component and will only include the impacts calculated for the same and not the entire automobile. Therefore, the impacts are calculated for individual component (FEM) in each phase including the use phase which generally dominates the life cycle.

6. Results and Life Cycle Impact Assessment

The LCA modeling was completed using SimaPro software v7.3 and the ecoinvent library v 2.0 was used for all the foreground and background data. Apart from Global Warming Potential (IPCC 100yrs method) and Cumulative Energy Demand (CED 1.02), other impact categories were analyzed as per the ReCiPe midpoint method. This report includes only GWP and CED results however; other results can also be made available on request.

6.1. Results

Figures 3 & 4 show the comparative results from the cradle-to-grave for STAMAX resin based FEM and PA-Steel FEM. The overall comparison reveals that the use phase is dominant and the lighter FEM made with STAMAX resin results in up to 48% lower carbon footprint and up to 43% less primary/cumulative energy demand as compared to the PA-Steel hybrid FEM.

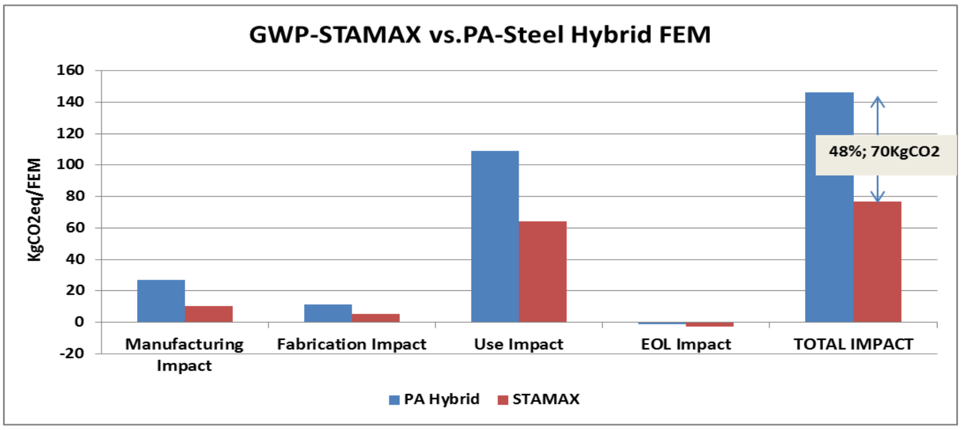

Figure 3 Avoided Emissions from Cradle-to-Grave phases of FEM (STAMAX vs. PA-Steel Hybrid)

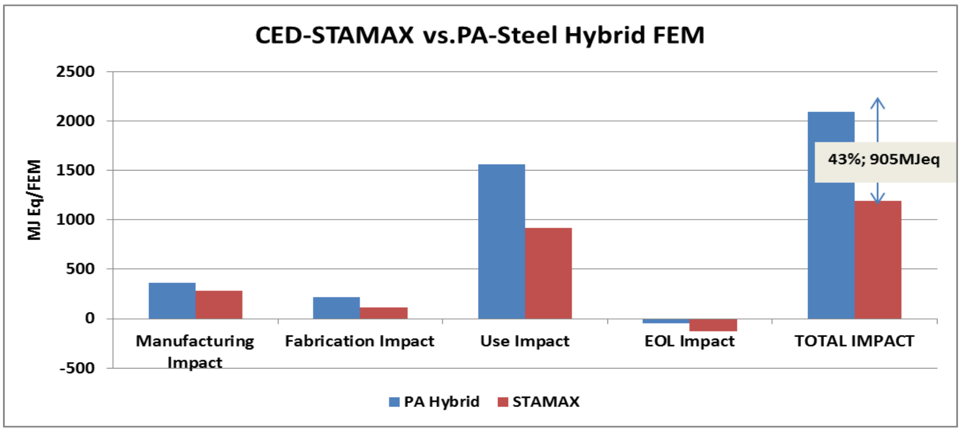

Figure 4 Avoided Energy from Cradle-to-Grave phases of FEM (STAMAX vs. PA-Steel Hybrid)

7. Significance of Contribution & Interpretation

7.1. Key parameters

Analyzing the above results reveals that PP based FEM avoids CO_2 emissions and reduces energy consumption in each life cycle phase, due to its light weight. In the material manufacturing phase, STAMAX has a lower impact because PP has a lower footprint as compared to PA and it uses less material to produce FEM. Steel, due to its recycling ability (~91%), does contribute towards compensating the higher impact in this phase; however the combined impact of the hybrid solution still remains high as compared to he PP solution.

In the fabrication phase the process yields play a major role. Since the injection molding process has a high yield (~98%) and is less energy intensive as compared to sheet metal stamping (70-80%), this phase also shows a lesser impact for STAMAX solution.

The use phase impacts are primarily due to fuel consumption accounting for the FEM component and related emissions such as CO_2. Again, the lighter weight of STAMAX FEM causes a decrease in impact during this phase and eventually dominates the whole life cycle impacts.

The End of life (EOL) burdens include impacts arising due to disposal of post-consumer material and reprocessing (sorting, separation and re-melting) and transportation of scrap materials. EOL benefits include avoided impacts due to recycling, recovery of materials or energy. Since the recycling benefits (avoided burden approach) of steel are already included in the material manufacturing phase, the grave phase included the reprocessing burdens and energy recovery benefits due to incineration of PA. For STAMAX resin based FEM, the EOL burdens included disposal of 50% material as landfill and incineration of the rest of the 50% part. The benefits came from the recovery of energy through incineration of 50% material. Since the PA-steel hybrid solution has only a 44% PA component, the resultant benefit of incinerating 50% of this material (Ref Sec.4) does not add much benefit to the EOL phase of the hybrid solution. Therefore, the PA-Steel hybrid part shows total lower impact in this phase as compared to STAMAX resin based FEM.

7.2. Significance of contribution

SABIC makes fundamental contributions to the value chain avoided emissions by manufacturing STAMAX resin, providing full part design and fabrication solutions for the FEM applications. As shown in sec. 7, manufacturing a lighter STAMAX resin for FEM application contributes towards avoiding emissions in every phase. However, the significant emissions are avoided through the use phase, which contributes about 68% to the total life cycle. The results are in sync with several publications[6] [7] [8] [9] which show that the use phase contributes up to 70% to the total life cycle in an auto application.

8. Attribution of avoided emissions to value chain partners

Qualitative assessment attribution: 70Kg CO2-eq emissions per FEM are avoided by using lighter FEM made with innovative STAMAX resin solution compared to heavier FEM made with PA-Steel hybrid solution during the life cycle of an average European[HM1] considered this study. SABIC makes two fundamental contributions to these avoided emissions by manufacturing STAMAX resin, providing full part design and fabrication solutions for the FEM applications.

9. Review of Results

SABIC is in the process of initiating the ISO critical peer review for this study to ensure that it is consistent with the LCA standards. It should be noted that results could change slightly based on peer review recommendations.

10. Integrating uncertainties and scenarios of future developments

A number of sensitivity cases were performed to analyze the impact on results due to varied assumptions. These included variation in weights, end of life scenarios, fuel type, FRV with no drive train adaptation and North America as a geographical region (refer App-A for summary charts). An uncertainty analysis was performed using the Monte Carlo simulation. It was observed that STAMAX solution performs better than PA-Steel hybrid solution in all the scenarios. Details of the analysis will be available on request.

11. Limitations, Conclusion & Recommendations

This study is specific to the parts studied and does not represent a comparison of plastic and metal parts in general. The current scope includes Europe & North America geographical use phase differences and should be adjusted to any other geographical scope.

This study emphasizes the importance of lightweight polymeric materials in automotive applications and resultant environmental benefits in terms of avoided emissions and reduced energy consumption. Replacing metal hybrid FEM by a light weight STAMAX resin based FEM avoids 70kgCO$_2$-eq emissions, which is made possible by novel PP and long glass fiber reinforced compounds combined with optimized part design.

12. References

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[1] Historically steel has other 50% market share; however, in recent years hybrid thermoplastics materials are dominant and steel is no longer a reference solution.

[2] Ridge, L (1998). EUCAR - Automotive LCA Guidelines - Phase 2. Society of Automotive Engineers: 193-204

[3] Borgne, R., Feillard, P. (2001). End-of-Life of a Polypropylene Bumper Skin. Int J LCA 6 (3) 167-176

[4] Dubreuil, A. et al. (2010). A Comparative Life Cycle Assessment of Magnesium Front End Autoparts, Society of Automotive Engineers:2010-01-0275, 2010,doi:10.4271/2010-01-0275

[5] Koffler C, Rohde-Brandenburger K (2010): On the calculation of fuel savings through lightweight design in automotive life cycle assessments, Int J LCA :15:128-135

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[6] Keoleian, G et al. (1998). Application of Life Cycle Inventory Analysis to Fuel Tank System Design. Int. J. LCA 3 (1) 18-28

[7] Ribeiro, C et al. (2007). Life Cycle Assessment of a Multi-Material Car Component. Int. J. LCA 12 (5) 336 – 345

[8] Puri, P et al. (2009). Life cycle assessment of Australian automotive door skins. Int. J. LCA 14 420-428

[9] Dubreui, A et al. (2010). A Comparative Life Cycle Assessment of Magnesium Front End Autoparts. Society of Automotive Engineers # 2012-01-2325

Appendix A: Sensitivity and Scenario Analysis

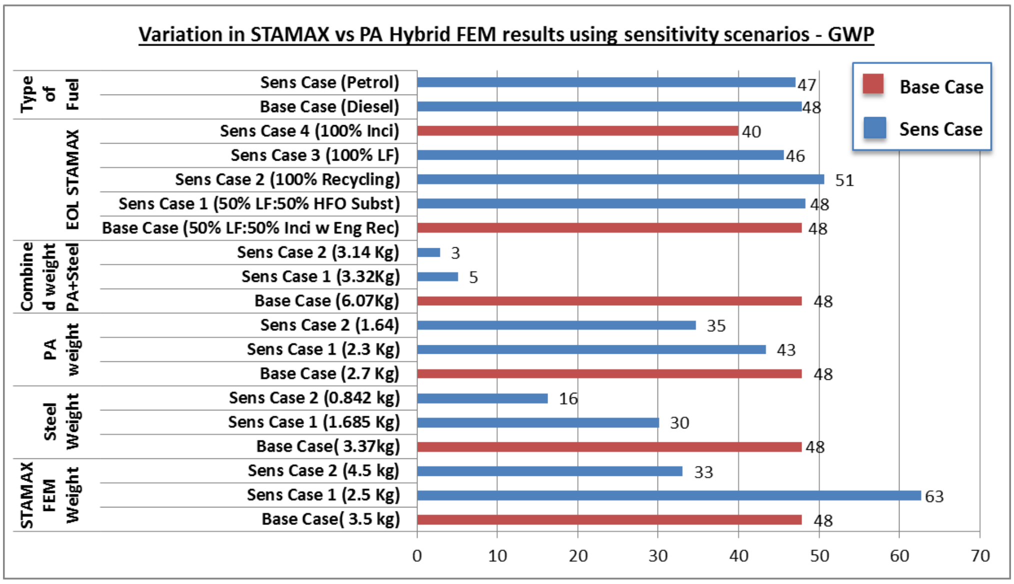

Figure A: %Difference between STAMAX resin based and PA hybrid FEMs using various sensitivity parameters- GWP

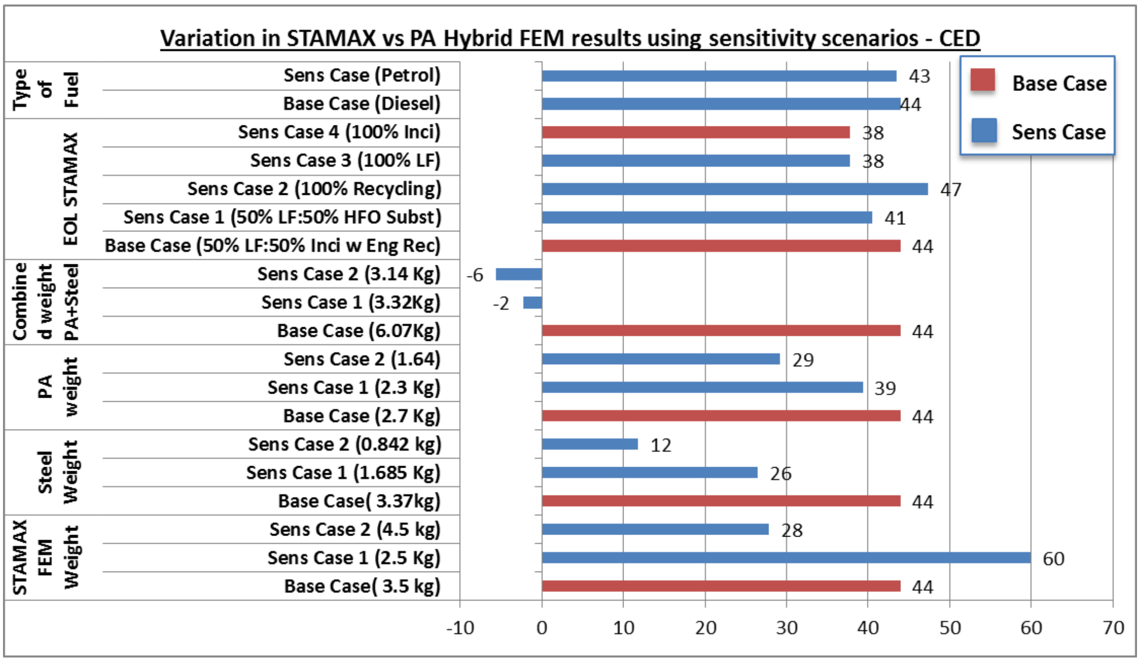

Figure B: %Difference between STAMAX resin based and PA hybrid FEMs using various sensitivity parameters- CED

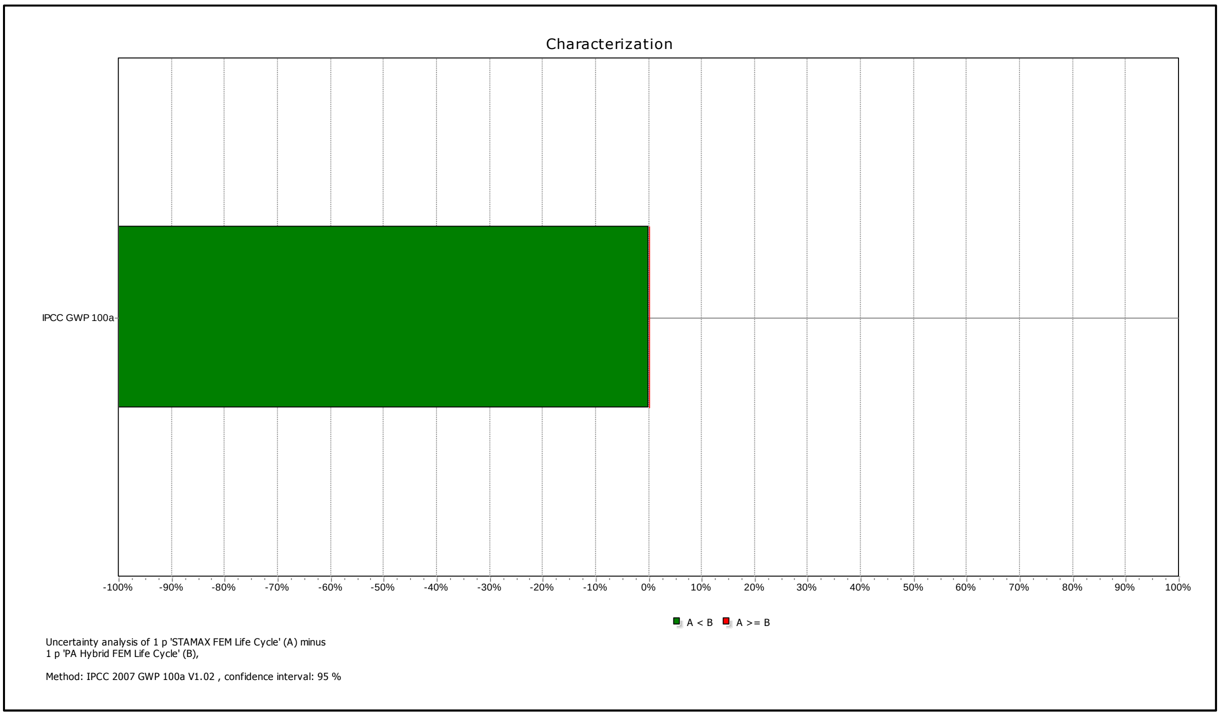

Figure C: Results of uncertainty assessment comparing 1 STAMAX resin based FEM (A) minus 1 PA (B), method: IPCC GWP 100a

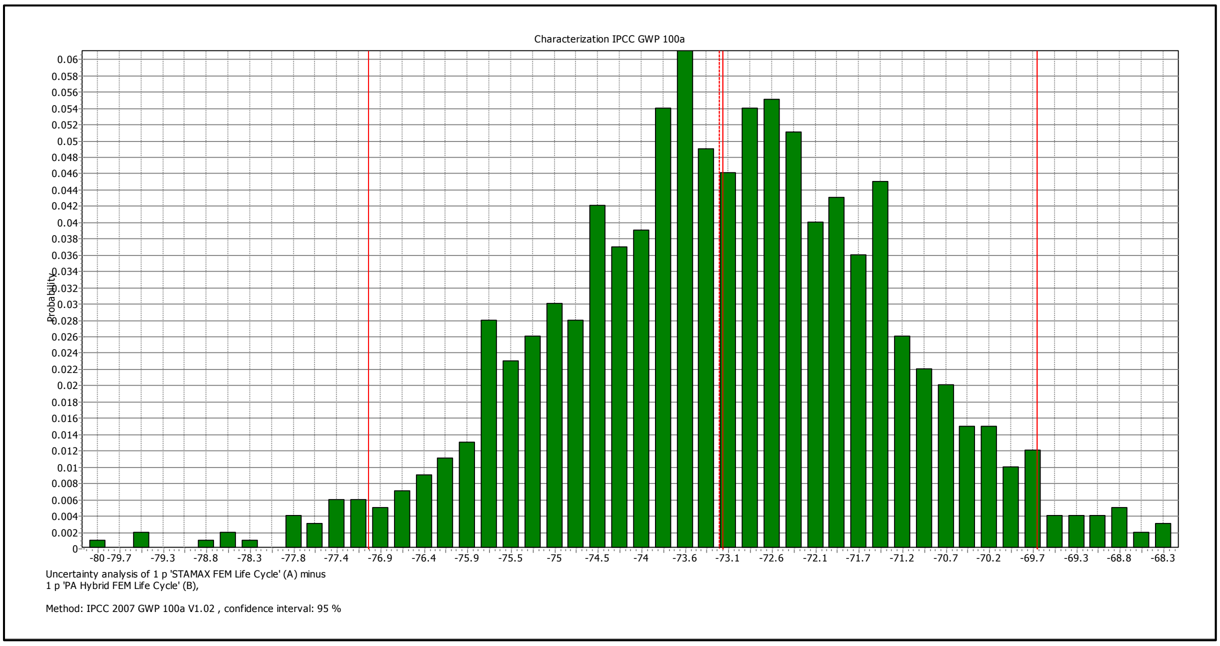

Figure D: Probability Distribution for 1 STAMAX resin based FEM (A) minus 1 PA (B), method: IPCC GWP 100a