A comparative life cycle assessment based evaluation of greenhouse gas emission and social study: natural fibre versus glass fibre reinforced plastic automotive parts

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Abstract: Current atmospheric CO_2 concentration in our atmosphere is already over 400 ppm, which is 50 ppm beyond our planetary boundary. Every single step towards reducing our carbon emission is important. Fuel saving due to the light weighting of the automotive materials will reduce greenhouse gas emission in the transportation sector, if the light weighting roots from a by-product natural fibre, such as sawdust or agricultural waste, the emission reduction would be more effective. The current study is a comparative life cycle assessment based evaluation of greenhouse gas emission of the current plastic engine beauty cover, and natural fibre reinforced counterpart. This study also analyses the questionnaire results gotten from 600 new car owners (or leaser) as a small sample of a buyer society.

Keywords: life cycle assessment; LCA; greenhouse gases; GHG; natural fibre; automotive parts; survey study.

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1 Introduction

Climate change could be considered to be the main cause of our ecosystem destruction. The emission of the greenhouse gases (GHGs) known to trigger climate changes. These GHGs mainly consist of carbon dioxide, methane, fluorinated gases and nitrous oxide and has a unit of carbon dioxide equivalents (IPCC, 2014). The Intergovernmental Panel on Climate Change (IPCC) restricts GHG emission in order to keep the global warming for a total value lower than 1.5°C to maintain our planet and make it a safe place to live (UNFCCC, 2015). Considering the timeline and total amount of carbon that we have left to release to maintain the 1.5°C, we have just five years or less to reach this limit. This new limit is a huge improvement from the previous 2°C, however, it is still not enough and only if we reduce our emission to 4% annually from now thereon, we will be able to see the year 2100 safely (IPCC, 2014).

US Environmental Protection Agency, (EPA) reported that about 20% of total CO_2 emitted is coming from burning petrol in cars and light-duty trucks (EPA, 2015). According to the available data an average personal vehicle (9.6 L/100km) in a year (20,000 km) will emit over 4.4 metric tonnes of CO2eq gases. As time goes by, the mandatory CO2 standards for new cars, (the amount of CO_2 allowed to release per kilometre of a car during its use phase) is becoming stricter. The allowed emission initially brought down from 140 g/km in the Kyoto Protocol (United Nations, 1998) to 120 g/km for the European Union to 95 g/km for 2020 (ICCT, 2014) is equal to the consumption of 3.8 litres fuel per 100 kilometres. Moreover, by the end of 2016, a new set-point will be established for 2025 which is going to be between 68–78 g CO_2/km and some countries like Germany are already pushing forward to set a new emission standard of 20 g CO_2/km for 2050 (Copenhagen Accord, 2009). EU has also set a maximum of 2.5 g/km per manufacturer per annum (ICCT, 2014).

It is obvious that light weighting is an important factor for the reduction of emission as, literally reducing the weight of a car by 10% and has shown to save up to 8% on fuel consumption. (Stans and Bos, 2007; Van Den Brink and Van Wee, 1999). In other words, for each 100 kg decrease of weight, there would be an estimated average of 12.5 grammes reduction in CO_2 emission per kilometre that an average gasoline vehicle runs (Stans and Bos, 2007; Brooke and Evans 2009). Not to mention the important fact that light weighting of around and on a powertrain (especially the engine area) is more valuable than that of other parts of a car. The reason is that there should be a maintained ratio of front to rear weight distribution in every car (Wordley and Saunders, 2006; Woods and Jawad, 1999) and for most modern cars, the engine is in the front. Reduction of weight from the rear section is easier than the engine area and therefore, reduction of weight in the rear of the car is limited for the fact that weight of the engine area's light weighting. Moreover, for every 1 kg light weighting of a powertrain, we can reduce the support weight by 0.2–0.3 kg as well, this is called secondary weight reduction or mass decompounding (Lewis et al., 2014). From the published literature to date, it is clear that there has been a moving trend in the part's materials from heavy metals to lightweight metal alloys, then there is also huge interest in the glass fibre reinforced polymer (GFRP) composites which are 20 to 35% light weighted compared to lightweight metal alloys (Das, 2011; Scuccimarra, 2012; Shaw et al., 2011) and finally to the natural fibre reinforced polymer (NFRP) composites and carbon fibre reinforced polymers. While carbon fibre seems to be very promising, it is still very expensive. NFRPs on the other hand, are not only inexpensive but also 20% lighter than GFRP, relatively a better crash absorber, a better sound insulator and finally, they help to save fossil fuels for a better use in the future (Alves et al., 2010; Faruk et al., 2012; Panthapulakkal and Sain, 2007). It has been shown that by replacing only half of the glass fibre reinforced plastics with natural fibre composites 3.07 million tonnes of CO_2 emission can be reduced and also, a 1.19 million m^3 crude oil can be saved (Pervaiz and Sain, 2003), this was only for North American automotive applications. What's more important is that there is a great potential in carbon storage of NFRP as this material holds carbon from natural fibres far longer than the natural fibres' decay or burning those as fuel (Pervaiz and Sain, 2003). This carbon storage is temporary only and it is limited to countries that landfill these materials.

The objective of this study is to investigate the GHG emission and global warming potential of the engine part under the bonnet, namely the engine beauty cover, made by two different composite materials and to investigate society's opinion on theses engine beauty covers. The composite materials used for manufacturing engine beauty covers are glass fibre reinforced polyamide composites and natural fibre reinforced polypropylene composites. The study covered the comparison from cradle to grave and the emission has been calculated based on fuel consumption savings because of the light weighting with and without considering powertrain adoptions, to compare greenhouse gas emissions of our new materials. Finally, we have discussed the results of our designed survey in the topic as an indicator of public opinion on the light weighting concept.

2 Methodology

2.1 Life cycle assessment

Life cycle assessment (LCA) is a powerful method (defined by ISO standard family 1404X) to evaluate the potential impacts of processes, goods, and services on our environment. LCA also enable us to compare products, processes, and services (ISO 14040). The LCA method contains four main steps:

a goal and scope definition

b inventory analysis

c impact assessment

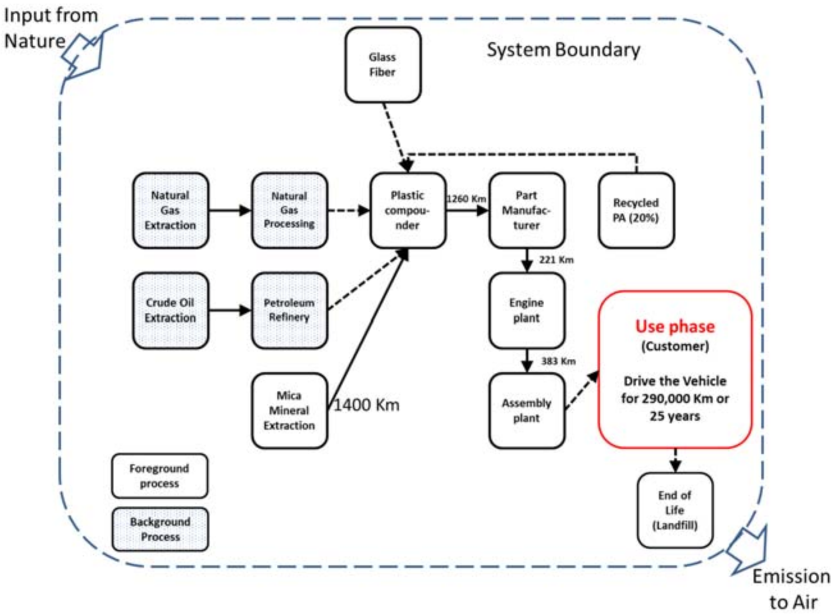
d interpretation.

There are some sub-steps mandated by the ISO standard, for example, in the goal and scope definition, one should include a description of the system boundary and the functional unit. The details are given in ISO 14044 and are beyond the scope of this paper. Goal and scope definition of this study is to compare the greenhouse gas emission from the current plastic engine beauty cover in comparison with the natural fibre reinforced counterpart.

2.1.1 System boundary

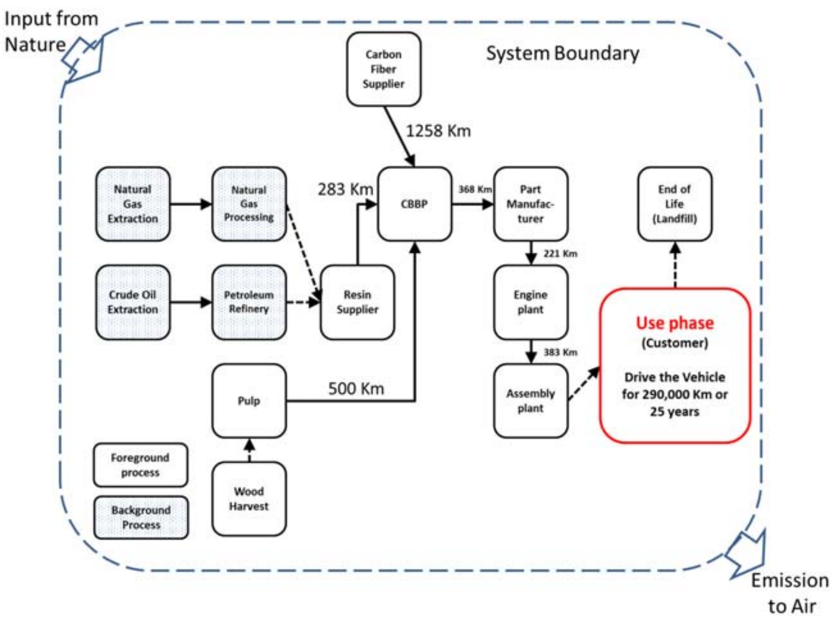
This study will look at the parts from cradle to grave, which means it starts from the extraction of necessary materials, including the growth of trees for cellulose fibre, extraction of oil and natural gases and finishes with emission and landfill. The system boundary and processes in the life cycle of bio-based and conventional engine covers are shown in Figures 1 and 2.

Figure 1 System boundary and processes in the life cycle of the conventional engine cover (see online version for colours)



Notes: Dashed lines are excluded from the calculations. Polymerisation steps have been done inside compounder facility.

Figure 2 System boundary and processes in the life cycle of bio-based fibre reinforced engine cover (see online version for colours)



Notes: Dashed lines are excluded from the calculations. Polymerisation steps have been done inside compounder facility.

2.1.2 Functional unit and scope definition

The Functional unit of this study is an engine beauty cover made generally to cover and protect a generic V6 engine of a Ford car (as an example), increase the beauty, isolate heat, and reduce noise for 25 years or mileage usage of 290,000 km. These are the numbers suggested for light trucks including pickup trucks, vans, and SUVs by The National Highway Traffic Safety Administration (NHTSA, 2006).

Reference flow for this study is one 957.98 cm^3 plastic engine beauty cover (bio-based or conventional), injection moulded and estimated to have a life span of over 290,000 km and will be shredded and landfilled after its life span. The total volume for each of these plastic parts is 957.98 cm^3 and fibre content has been evaluated based on the weight. 30wt% (glass fibre and mica group minerals) assumed performs similarly to 30wt% (cellulose fibre and carbon fibre) (Table 1). Both designs meet manufacturer's standard specifications.

Table 1 Material composition for two engine beauty covers used in this study

Materials	*Weight*	*Fibres*	*Matrix*
Currently used (conventional) engine beauty cover (10% glass fibre + 20% Mica) reinforced polyamide (PA6) which has 20% recycled content + proprietary additives	1,322 g	132 g glass 264 Mica mineral groups	185 g Recycled PA 740 g Virgin PA + up to 5% proprietary additives
Bio based engine beauty cover (20% cellulose fibre, 10% carbon fibre reinforced polypropylene + proprietary additives)	992 g	198 g Cellulose 99 g Carbon	665 g PP + up to 5% proprietary Additives

2.1.3 Method, assumption, and impact limitations

This study only focuses on the greenhouse gas emission and only follows the scenario that this engine beauty cover is sent to landfill at the end of its life cycle as this is what is currently happening to most of the plastic composite parts in North America (Stagner et al., 2013; Miller et al., 2014). It is also assumed that the engine beauty cover will be sent to only one engine plant (average distance of the actual plants) and the distances from the assembled car to a dealer and a customer were not calculated. There was no secondary mass change in our scenario and for this sort of prototyping the original equipment manufacturers (OEM) prefers to keep their current designs for simplicity to avoid multiple design change. In this study, powertrain adaptation was provided for comparison. The fuel used in this calculation was standard E10 petroleum, which is petrol that contains up to 10% ethanol and emits 2.3 kg CO_2eq for each litter it burns. For both engine covers, there were up to 5% proprietary additives which due to limitations were not considered in the calculations. For the glass fibre reinforced plastic, there is a 20% recycled content as was mentioned in the material data sheet and considered in the calculations. The air conditioning refrigerant could also lead to a global warming potential in cases of leakage and emission of 1 gram of these materials (HFC-134a) which is 1430 times more harmful than the emission of 1 gram of the CO_2. But because we compared the two counterparts, and we were not certain if a leak might occur, therefore was not considered in the calculations.

Required data categories used were both primary and secondary data and the flow data were chosen based on:

1 representing all the major gases that have a global warming impact as indicated by TRACI and IPCC (Bare, 2012; IPCC, 2014)

2 the availability of data in the databases.

To model the life-cycle impacts, a modified TRACI 2.1 characterisation model factors were used for analysing the global warming effect. This model used updated characterisation factors based on the 2013 IPCC AR5. The oil well to pump data for fuel saving was gathered from the GREET database (Wang, 2012). Data collection was not done directly on the landfill, but the generic inventory data was collected from Gabi's databases (Think step, Germany, 2015), US LCI (NREL), Ecoinvent 3, and ELCD 3.3. In this study, only the emission contributing more than 1% to system total flow of air emission was included in the model and in order to comply with the ISO 14044, Section 4.2.3.3 we have included energy and environmental relevance, to our analysis as well.

2.1.4 Logistics data

Logistics data collected was based on the real distance between the gates. The total trip for the main materials is summarised as follows:

Minerals transported with an average distance of 1,400 km to the plastic compounder goes from there on for another distance of 1,260 km to the parts' supplier with the ratio of 1:5 (for each truck of minerals that goes to the compounder, five trucks of ready to use plastic goes to parts' manufacturer). The minerals are shipped by trucks, whereas ready for injection mould plastic materials are shipped by train from the plastic compounder to the part supplier, where the engine beauty covers are thereafter moved by trucks to the engine plant. Based on the standard container's measurement of size and weight, it was estimated that a total of 360 covers will be carried by each truck. The assembled engines are then moved by trucks to the assembly plant.

2.1.5 Multi-functionality and allocation

In the production of pulp, there is a case of multi-functionality as the wood fibre used is a by-product of products like construction wood, pulp, and paper. For plastic production, based on the database information, there was an allocation for the portions of flow based on the mass, therefore, the system expansion by substitution approach was engaged to avoid cardboard and skid recycling.

2.1.6 Data quality requirements

This study has a geographical coverage of Canada and/or the North American system. All data gathered were dated within the past 10 years for more accurate emission. In terms of technology mix, all data was based on an average North American technology. Life cycle inventory data were collected based on collaboration with the part manufacturer, material suppliers, and researchers. For some of the data that there were no North American data available the European data was confirmed by Canadian source and has been used instead.

Table 2 Inventory of materials for the engine beauty covers

Current materials	
Glass fibre	0.132 Kg
Mica	0.264 Kg
Virgin polyamide	0.740 Kg
Recycled polyamide	0.185 Kg
Bio based materials	
Cellulose fibre	0.198 Kg
Carbon fibre	0.099 Kg
Polypropylene	0.665 Kg

2.1.7 Inventory

The inventory of conventional materials and biomaterial based engine cover used for production phase calculation could be seen in Table 2.

2.2 Description of the system and life cycle

2.2.1 Production phase

For production phase, the data was calculated from both primary and secondary sources. Each component of the bio-based fibre reinforced and conventional composite materials were added together to find the total emission, which includes transportation and also compounding. It has been reported by Cause Canada that the usage of 1 kg of recycled plastic instead of the virgin materials emits 2.5 kg less CO_2eq (Cause Canada, 2015) and there are reports of reduction of 13% in GHG by using recycled PA 6 (Lartigue and Viot, 2012). According to US EPA, the net recycling emission for a mix of very similar material (PA 66 and PA 6) is 2.36 (USEPA WARM 13, 2015) and therefore we also assume that 2.36 is the case here as well which is almost 14% reduction. This was used as the basis for calculation of recycled content; this emission was reduced from the total emission for the current plastic part. The average fuel consumption of the Ford Motor vehicle was evaluated based on the sales data available to the public, published fuel economy and Canadian average fuel consumptions.

2.2.2 Use phase

The use phase has been calculated based on the CSA LCA guideline (CSA SPE-14040-14) which is according to the standard, 290,000 km for light-duty trucks and SUVs. The GHG emission is calculated and compared based on the fact that burning of 1 litre of Petroleum will emit 2.3 kg CO_2eq.

2.2.3 End of life

Although there have been numerous outstanding research studies on the end of life and recycling of vehicle's plastics. In reality, most plastic parts, especially the fibre reinforced plastics in North America will be an automotive shredder residue which will be sent to the landfill (Stagner et al., 2012). The main reasons that these materials have not been recycled are the complexity of the recycling process, lack of cost worthiness as well as unestablished methods for burning fibre reinforced plastics into energy. Another reason which does not apply to our engine cover is that dismantling process is hard for plastics, especially when they are out of reach (Khabiri 2014; Stagner et al., 2013; CELA, 2011; Toth et al., 2014; Bandivadekar et al., 2008). Therefore, it was assumed that plastic parts are not recycled at the end of the vehicle's service life and will be sent to the landfill, which is expected to cause a minor greenhouse gas emission over the 100 year time horizon (Waste, 2009; EPA, 2014; Al-Salem et al., 2014).

2.3 Sensitivity analysis, scenario analysis, and uncertainty analysis

Because of assumptions and uncertain nature of the LCA and as it is required by ISO and CSA LCA guideline, an uncertainty analysis was performed on the collected data (ISO 14044:2006; CSA SPE-14040-14). Scenario analysis is basically a comparison of our emission results with the results calculated based on the altered assumptions. For example, the mileage of a vehicle may never reach 290,000 km, therefore we need to calculate the data based on 250,000 km (which is equal to the end of life for a passenger car) as well and then compare the two results, this is also called scenario analysis, the result should be considered significant if the difference is more than 10% (CSA SPE-14040-14). Besides vehicle mileage, using different materials, change in designs, and manufacturing processes, also electric power grid mix, fuel sources and even recycling scenarios may be considered in the scenario analysis (ISO 14044:2006).

2.4 Social study

A questionnaire was prepared with 21 questions (Appendix 1) to determine the costumers' opinion on the light weighting, fuel saving, and emission. These questionnaires were distributed to five different Canadian regions and cities, namely: Greater Toronto Area, Hamilton, Windsor, Cambridge, and Welland, all located in the province of Ontario. By choosing these cities we tried to cover not only vast geographical area of the province but also a city population range of 50,000 to over 6,000,000 people to study whether living in a bigger city affects the buyer's perspective. To qualify for the survey, respondents were at various automotive authorised sellers and purchasing or leasing a new vehicle (different makes and models). We only included the buyers with the final prices between 30,000 to 40,000 USD to avoid confusion. Surveys with unanswered questions were removed and replaced by new respondents to keep the respondent population at n = 600. The questions were designed deliberately to measure a single factor by asking the same question in different ways (Appendix 1).

3 Results and discussions

3.1 Data quality assessment

The data quality assessment was done as described by Weidema and Wesnaes (1996). Table 3 indicates the quality assessment indicators and the correspondent scores. The quality of data was considered good based on the scores. In this system, data was scored based on the quality parameters from best (1) to worst (5); detailed information is available in the reference (Weidema and Wesnaes, 1996).

Table 3 The data quality check was done based on the Weidema and Wesnaes (1996)

Data quality indicator	*Score*	*Explanation*
Reliability	2	Part of data based on assumptions
Completeness	2	Complete
Temporal correlation	3	The data are less than 10 years old
Geographical correlation	3	All data are from North America, except for landfill data which was from Europe, but it was verified by Canadian practices
Technological correlation	2	Data are average recent technology mixed from North America

3.2 Calculation

For the use phase (driving cycle) calculation, the source of the data were based on the US EPA fuel economy certification data for internal combustion engine and federal test procedures and standardised drive cycle based on calculation of city/highway driving cycles (55% city driving and 45% highway driving) (EPA; FTP). An average Ford SUV/light-duty truck with the current (conventional) engine cover within the use cycle (290,000 km) will burn 29,000 L of petroleum E10 (9.8 L/100 km which was rounded to 10 L per 100 km).

One simple way to calculate the fuel saving is grounded to the fact that in the light weighting process, for each 10% of dropped weight, the vehicle will have up to 8% fuel savings (Stans and Bos, 2007; Van den Brink and Van Wee, 1999). So, for a kerb weight of 2000 kg which is the average kerb weight of the SUV/light-duty trucks with the same engine cover, (the light weighted beauty cover is 330 g lighter) the vehicle will be 0.0165% % lighter. This light weighting at the best case will lead to 0.0132% % fuel savings (0.0165% ∗ 8% / 10%) or 3.828 L of petroleum for the total driving cycle of the vehicle, which is the best case theoretical evaluation. It has been shown that the combustion of 1 L petroleum will result in 2.3 kg CO_2eq (2289 g CO_2 + 0.14 g CH_4 + 0.022 N_2O) (Environment Canada, 2011). Based on these calculations, saving of 3.828 L of petroleum leads to a reduction of 8.805 Kg CO_2eq. This method may not be really exact as the weight of the car with an engine cover may be very different, therefore alternative method endorsed by CSA to determine the minimum fuel saving as well was adopted:

Based on CSA's method and 'assuming no powertrain adaptation', the minimum total fuel consumption change is as follows:

$$C_{WA,p} = \left(m_p - m_b\right) \times F_{CO} \times LTDD_V$$

where,

$C_{WA,p}$ the minimum total life cycle mass-induced fuel change in litres

m_p mass in kg of the new auto part

m_b mass in kg of baseline auto part

F_{CO} mass-induced fuel consumption value, without adaptation, in l / (100 km · 100 kg)

$LTDD_V$ baseline vehicle lifetime driving distance, in km (Lifetime driving distance is 250,000 km for passenger vehicles with internal combustion engines and 290,000 km for light trucks including pickup trucks, vans, and SUVs (NHTSA, 2006).

So for the bio-based fibre reinforced engine cover, considering the engine type and no powertrain adaptation total fuel consumption change is:

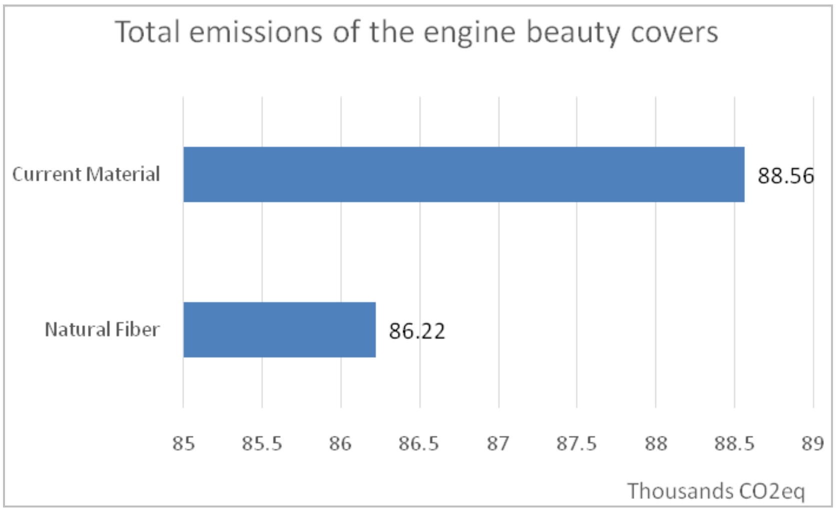
$$(0.992 - 1.322)\text{kg} * 0.168 \text{ L} / (100 \text{ km} \times 100 \text{ kg}) \times 290{,}000 \text{ km} = -1.608 \text{ L}$$

And with the powertrain adaptation (best case scenario and highly unlikely) the change will be:

$$(0.992 - 1.322) \text{ kg} * 0.40 \text{ L} / (100 \text{ km} \times 100 \text{ kg}) \times 290{,}000 \text{ km} = -3.828 \text{ L}.$$

which is the same as the first calculation.

Figure 3 The graph for CO_2eq emission for two engine covers (whole life cycle), CO_2eq consists of carbon dioxide, methane, and nitrous oxide (see online version for colours)



Thus saving of fuel during the use phase equals to the emission of almost 3.7 kg CO_2eq and in best case scenario 8.8 kg CO_2eq (with a powertrain adaptation) less than the conventional engine beauty cover. Further, based on the inventory, natural fibre reinforced plastic will emit 3.78 kg CO_2eq less than a regular glass fibre reinforced plastic during the production and the end of life phase (Akhshik et al., 2017). Therefore, a total of 7.48 kg CO_2eq can be reduced from our emission by using the new engine cover. Considering the amount of fuel that is needed at the petrol stations, the emission will be up to 9.09 kg CO_2eq less than the glass fibre counterpart. Although this number seem very low especially for a whole life cycle of a vehicle, these reductions in emission will add up quickly if we consider the rounded up total number of cars produced in one year with these engine beauty covers:

$9.09 \text{ kg } CO_2\text{eq} * 1{,}000{,}000 \text{ cars} = 9{,}090 \text{ tons of } CO_2\text{eq},$

Which is a significant reduction of emission in the transportation sector, and here we are only talking about 1 model engine, by replacing these materials for all the engine cover we will have a very big number. Figure 3 illustrates the emission of bio based (NFRP) composite in comparison with the conventional material (GFRP).

For the use phase of the SUV/Light-duty truck, it was estimated that the vehicle will burn 10 L petrol per each 100 Km and therefore for the whole life cycle the vehicle will burn 29,000 L of petrol and will emit 66,700 Kg CO_2eq (29,000 * 2.3 Kg CO_2eq). Based on the calculations our light weighted vehicle will emit 66,691 Kg CO_2eq and to make it more accurate we need to consider well-to-wheel emissions as well. The total emission can be seen in Figure 3.

In summary, the natural fibre composites emit 0.026% less CO_2eq GHGs than the glass fibre composites. Although it may seem a low number, considering the facts that this is only for one single part and if we multiply all the vehicles produced last year used the new materials (only for one model and one single part) at the end of their lifetime for each single year, we will be emitting 9,090 tonnes of CO_2eq less than what is happening right now. Landfilling of plastics considered emitting nothing based on Gabi's database and other sources have been mentioned methane as the main greenhouse gas and the other gases are insignificant (Bogner et al., 1999; Rinne et al., 2005). However, databases mentioned that landfill of 1 kg polypropylene will emit from 0.044 g to 4.310 g CO_2eq due to the landfill operations. In this study, we have included the landfill of engine beauty covers and subsequent emission of GHGs. However, We are aware of the fact that this landfilling may not happen to actual parts at the end of the lifetime, as these engine beauty covers will last till 2040 and by then, a full recycling will be required and probably no landfilling is allowed for materials of the kind.

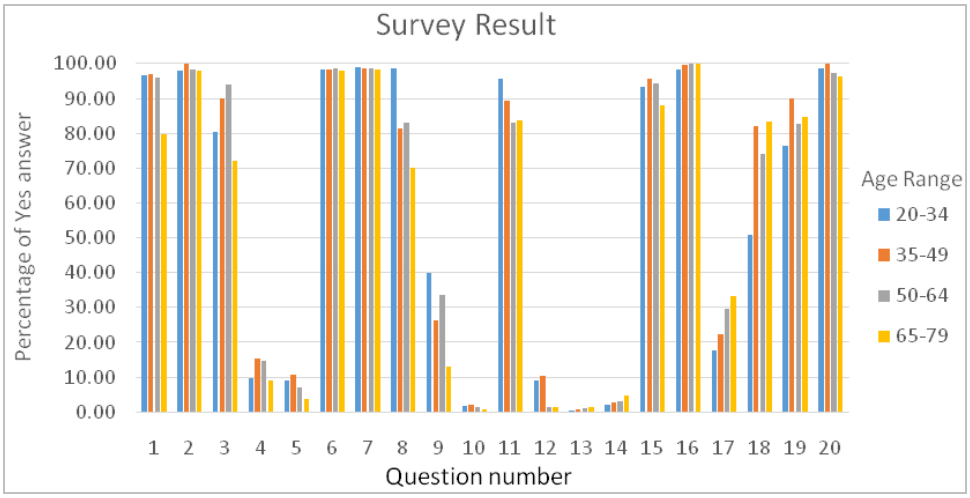
3.3 Sensitivity analysis, scenario analysis, and uncertainty analysis

A scenario analysis based on the 'end of life' data has been done on emissions with Crystal balls v11.1.2.4 (ORACLE, USA) and results prove that our data is reliable and there might be a variance less than 1% in our data. There was also an uncertainty analysis for different electricity grid mix and the result was below 10%. For the vehicle lifetime driving distance of 250,000 km there was another analysis as advised by NHTSA (2006) and CSA SPE-14040-14 and here our car will obviously have a lower total fuel saving (~13.8%) and it will, however, burn 4,000 L less petroleum.

3.4 Survey results

In terms of the city population, ironically, living in small or bigger cities did not show a significant difference in our results. This could due to the advent of the communication technologies and the fact that nowadays, people receive the same data and information over the media in different cities.

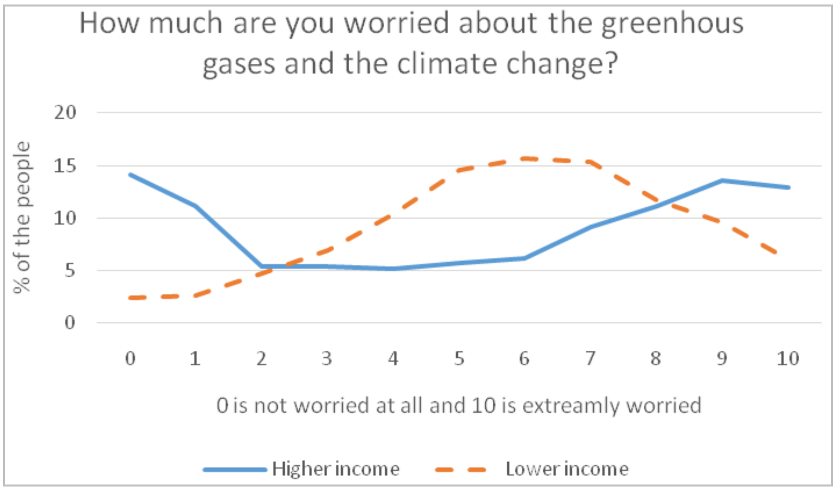
Figure 4 Results of survey questions presented here (see online version for colours)



Note: For the questions please refer to the Appendix 1.

Although questions cover the same concept but asking it in different ways results in totally different responses (Figure 4). For example, questions 13, 14, 15, and 16 are conceptually the same as 17, 18, 19, and 20 respectively. While to the question 'Do you consider choosing an option for your car (same brand, model, performance, and price) that helps your car to consume 3 litres less fuel within the whole life?' only 0.96% ± 0.37 of the total buyers answered yes. Then to the same context 'Do you consider choosing an option for your car (same brand, model, performance, and price) that helps your car to emit 10 Kg fewer GHGs within the whole life?' 25.71% ± 7.00 answered yes. After revealing the fact that these questions and contexts are the same to the participants, some mentioned that they never knew 3 litres of fuel could emit that amount of greenhouse gas and some even mentioned that they thought at most 3 litres of fuel will emit 3 grams of CO_2. This means that people possibly correlate more with the words like 'less greenhouse gas emission' than 'less fuel consumption'. Another mentioned reason was the fact that by a simple multiplication they realise that their car could save less than 3 USD for the whole life and they think that this amount is not rewarding enough to experience an unknown. However, when we talk about 300 litres less of fuel, they considered the fact that this car could save less than 300 USD which many found lucrative enough to give the lightweight car a try. The other major observation was in the lightweight option for the same model. While many agreed that 0.5% less weight is totally acceptable, many found 25% of weight reduction, uncomfortable. The results suggest a significant difference amongst different generations, for example, within the group age of 20–34 years, they felt better towards having a car that is 5% light-weighted while others were not comfortable with the 5% decrease. Ironically within the same group, only 51% responded yes to the question: 'Do you consider choosing an option for your car (same brand, model, performance and price) that helps your car to emit 10 Kg fewer GHGs within the whole life?' while in other age groups 79.83% ± 5.09 answered yes, and this is against the fact that for most of the questions, the older the age group, the more conservative they become.

Figure 5 Distribution of the people based on the question 21 (see online version for colours)



Note: As you can see higher income households shown a bimodal distribution and lower income household showed a normal distribution.

One of the interesting results found was for that of question 21 and made even more interesting by combining the results with the average household income of the participants. As you could see in Figure 5, by increasing the household income, we see a clear cleavage and the data thereafter shows a bimodal distribution or literally, people with higher income in our survey were either extremely worried about the greenhouse gas or not worried at all. While in lower household income, we do not see the same pattern and the data thereafter followed almost a normal distribution.

4 Discussions

We followed two scenarios in this study for making an under the bonnet part, one using glass fibre reinforced polyamide and the other, using natural fibre reinforced polypropylene. Based on the calculated numbers from LCA, it was shown that natural fibre reinforced composite part is more efficient in terms of the greenhouse gas emission. These results are in compliance with other works (Luz et al., 2010; Joshi et al., 2004; Boland et al., 2014; Batouli et al., 2014a; Xu et al., 2008). Glass fibre production needs a temperature treatment (1,550°C) which is energy intensive and is a source of significant GHG emission (Kellenberger et al., 2004). While production of the carbon fibre is also very intense in terms of energy (1,800–2000°C), it was shown that it could be balanced by the reduction in the emission from natural fibres. There are reports on the fact that using carbon fibre will not be environmentally friendly, for example, it has been reported that using carbon fibre reinforced plastic in a floor pan has increased the life cycle energy by 3% (Das, 2011), on the contrary, results of the study suggests that mixing carbon fibre with natural fibre will mitigate the problem. By just simply substituting the new materials even though they contain up to 10% of carbon fibre, which emits a large portion of the total GHGs, we could still emit 9.09 Kg CO_2eq less for the total life of the vehicle, which will be a significant reduction if we multiply this number by the total number of cars produced. This reduction is equal to almost 0.026% less GHGs over the lifetime of the car for only one part, an average car has a lot of components which are currently made of GFRP and by replacing many of these components, the weight reduction percentage will dramatically increase. There is a small difference between our estimates and a similar work reported by Boland et al. (2014). This is caused by using different materials, like including carbon fibre (which has higher energy consumption and will emit more greenhouse gas) and mica group minerals and other details. The difference in the system boundaries could be another reason for such differences.

One of the very important factors that need to be considered when using natural fibre is the sequestration of carbon by holding the carbon inside a durable part. In general, natural fibres turn back to CO_2 as biodegradation occurs or even if it is used as a non-durable product like mulch and animal beddings. Turning the fibres into durable products like beauty cover is the true carbon saver for at least 25 years. Carbon which is captured within these products will not be released soon, especially if they end up in the landfill. However, some researchers consider these, as a temporary and short effect. In general, if the carbon is released within 100 years they do not consider it as a real carbon saving unless they stay in the landfill for over 100 years or use a different global warming potential frame like 20 years instead of 100 years (Shine et al., 2005).

We finalised our study with a survey on the light weighting concept, fuel savings, and GHG emission, the questions in this survey were designed to reflect the ideas on the subject on newly purchased car owners. Although surveys are one of the most important tools available for such studies, questions inside will have a huge effect on the results.

In our survey, we found out that people who had a high income and bought luxury cars tend to move towards both ends of the scale when asked: 'how much are you worried about the greenhouse gas emission and global warming?' This group forms a bimodal distribution while lower income equivalents are more likely to form the normal distribution. A Canadian survey which asked 'on the purchase/lease a new vehicle, was the fuel efficiency an important decision factor for them or not?' concluded that for 15% of the population, the fuel efficiency is not a decision factor (Canadian Vehicle Survey, 2009: Summary report) and here we also have comparative results. Our survey also showed that, the buyers, do not always correlate the fuel economy with the GHG emission.

5 Conclusions

While Standards mentioned that, fuel consumption value as a result of light weighting is between 0.161 to 0.40 L/ (100 km 100 kg), this only contains part of the actual fuel savings, for example, just saving 1.608 liters of fuel per vehicle per its lifetime will have an additional reduction of 1.61 Kg of CO_2eq on transferring that amount of fuel from oil extraction site to petrol station, and this is only for one vehicle. Our light weighting scenario simply ignores the secondary weight reductions and we included the fuel saving method based on the vehicle life service and also the reduced amount of fuel from well to pump. If we multiply these numbers by the total number of cars produced with the same engine beauty cover (approximately 1,000,000) we could save over 9,090 tonnes of CO_2eq emission per year for just simply replacing current materials. Although all these small steps are important at the end, but presentation of this data to the public could make a key difference, as it was discovered in our survey, most people considered themselves 'environmentally aware', however only a fraction knew that 1 litre of fuel will emit over 2 kg of CO_2eq GHGs. Another key finding was that although people may be interested in light weighting, they are deeply worried about the performance of their vehicles and their components. During the survey, people mentioned final price tag is a determining factor and if the lightweight cars come with a cheaper price, they would consider it seriously. One major feedback from the contributors was the fact that people worried about the car's performance and expected additional warranty for the available options. Another major concern was the fact that lighter cars may affect the driving experience, especially with wind while driving on the motorways.

It is obvious that the key to having a better fuel efficiency is in the light weighting. As the government and customers push for a greener car, the OEM already feels the necessity to shift to materials like natural fibre reinforced plastics. It is very important to consider all other impact categories for LCA and having a complete study before making any decisions as there are reports on the effect of natural fibres on eutrophication (Martínez et al., 2007; Batouli et al., 2014).

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Appendix

1 Do you consider yourself an environmentally aware person?

2 Do you usually recycle?

3 Do you prefer buying green products?

4 Do you consider buying a different car if it was labelled greener than the current car you are buying?

5 Do you consider buying a lighter car to save on fuel within the same class of car?

6 If a lightweighted option (1 kg or 0.05%) was available to your car would you consider buying that (without a price change or a compromise in safety and performance)?

7 If a lightweighted option (10 kg or 0.5%) was available to your car would you consider buying that (without a price change or a compromise in safety and performance)?

8 If a lightweighted option (100 kg or 5%) was available to your car would you consider buying that (without a price change or a compromise in safety and performance)?

9 If a lightweighted option (500 kg or 25%) was available to your car would you consider buying that (without a price change or a compromise in safety and performance)?

10 If a lightweighted option (1000 kg or 50%) was available to your car would you consider buying that (without a price change or a compromise in safety and performance)?

Do you consider choosing an option for your car (same brand, model, performance, and price) if you know within the same price range:

11 You will have a car which one plastic component is bio-based?

12 You will have a car which all the plastic components are bio-based?

13 Your car will consume 3 litres less fuel within the whole life?

14 Your car will consume 30 litres less fuel within the whole life?

15 Your car will consume 300 litres less fuel within the whole life?

16 Your car will consume 3000 litres less fuel within the whole life?

17 Your car will emit 10 Kg fewer greenhouse gases during its whole life cycle?

18 Your car will emit 100 Kg fewer greenhouse gases during its whole life cycle?

19 Your car will emit 1000 Kg fewer greenhouse gases during its whole life cycle?

20 Your car will emit 10000 Kg fewer greenhouse gases during its whole life cycle?

21 On the scale of 0 to 10 please rate how much are you worried about the greenhouse gas emissions and global warming? (0 indicates not worried and 10 being extremely worried)?