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Integration of novel nano materials into existing production lines

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Acronym: OptiNanoPro

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Publishable Executive Summary

Goal and scope

The environmental and economic impact of the OptiNanoPro door panel is investigated following the LCA approach. All life cycle phases from cradle to grave are taken into account, wherever possible based on process data provided by the OptiNanoPro consortium members completed with process descriptions from the Ecoinvent 3 database.

The OptiNanoPro door panel evaluated in this study is a PP/PE polymer with glass bubbles and nanoclay to lower the weight. The reduced weight is expected to lower vehicle fuel consumption and as such improve the associated environmental footprint and economic costs of transportation.

Environmental impacts are calculated using the IPCC 2013 100a and ReCiPe 2016 (H) endpoint impact assessments methods for determining climate change impacts, damage to ecosystems, damage to human health, and resource depletion. Economic impacts are calculated by economic costs expressed in euros (2018 value).

For the use stage of the door panel only the mass dependent part of the emissions of driving a car was taken into account. This is 70% of the emissions caused by fuel combustion and 100% of the brake, tyre and road wear emissions.

Results and discussion

The total environmental impact of the OptiNanoPro door panel is around 13% lower than that of a normal mass door panel in all four considered impact categories (Figure 1). The improvement is mainly caused by the lower driving emissions due to the reduced weight of the door panel.

The environmental footprint in terms of climate change, damage to human health, and damage to ecosystems is mainly caused by fossil carbon dioxide emissions. Most of these emissions originate from the combustion and the production of fuels. In terms of resource depletion, the use of crude oil for petroleum production needed for fuels and PP is the main impact source.

Also from an economic point of view the OptiNanoPro door panel performs better than the conventional one when looking at the total life cycle of the product. The higher production costs are compensated by the lower fuel consumption costs caused by the lower weight of the door panel leading to a 4% reduction in life cycle costs.

Conclusion

It can be concluded that the door panel developed within the OptiNanoPro project looks promising for improving the environmental impact of passenger cars thanks to their reduced weight. From a cradle-to-grave perspective, also the economic costs of the door panel are improved.

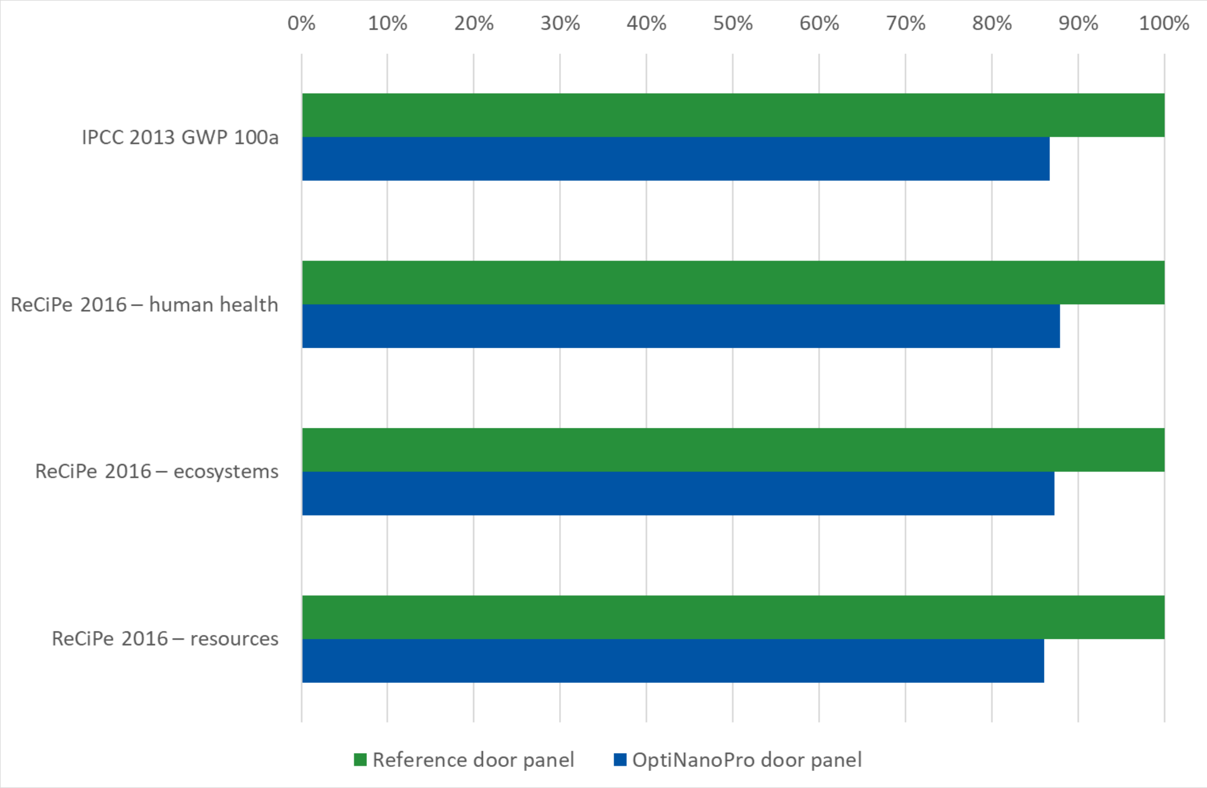

Figure 1: Relative results of the impact assessment for the reference scenario and the OptiNanoPro product

1 Goal and scope definition

1.1 Goal

The goal of this study is to evaluate the environmental and economic sustainability of the door panel developed during the OptiNanoPro project following the environmental life cycle assessment (e-LCA) and the life cycle cost analysis (LCCA) approaches. The total environmental impact and the economic cost are calculated and the hotspots throughout the product life cycle are identified. This should allow the identification of potential further improvements in terms of the environmental and economic sustainability of the product. The results are also compared to a standard polypropylene door panel (business-as-usual).

This deliverable is first of all intended for the partners of the OptiNanoPro consortium and the European Commission who supported this work. Secondly, it is a public report available for anyone interested.

1.2 Scope

1.2.1 System boundaries

For this report a cradle-to-grave approach was used for the production of the door panel, starting with the extraction of natural resources and ending with waste treatment in the end-of-life phase. The system boundaries of this process are illustrated in Figure 2.

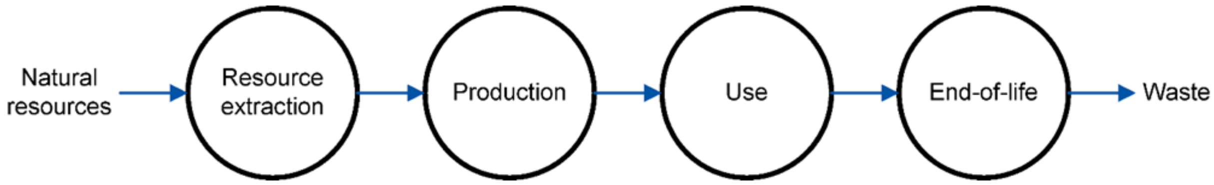

Figure 2:Cradle-to-grave life cycle

1.2.2 Functional unit

The functional unit is the reference to which inputs and outputs are related. This reference is necessary to ensure comparability of the results. It should be easy to interpret by all interested parties and easy to draw practical conclusions from.

The functional unit chosen is one door panel of an average passenger car.

1.2.3 Methodology

Environmental impact

The environmental impact was calculated with SimaPro (version 8.5.2.0) using two methods. First of all the impact on climate change was calculated using the IPCC 2013 method (GWP 100a V1.03), the standard and most recent method. Secondly, the ReCiPe endpoint method (hierarchic) was used to calculate the results in three endpoint categories: damage to human health, damage to ecosystems, and depletion of resources. In the next paragraphs a brief introduction to these two methods is provided.

Changes in atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land cover and solar radiation alter the balance of the climate system. This leads to the warming of the climate system which is proven by observations of increases in global air and ocean temperatures, the rising of the global average sea level and the melting of snow and ice. This has an impact on water, weather, ecosystems, food production, coastlines, health, tourism, infrastructure, etc. [1] The standard method for measuring climate change in LCAs is the baseline model of 100 years of the International Panel of Climate Change (IPCC). Although the time frame of 100 years is adopted as basis, also 20 years or 500 years can be calculated [2]. GHGs have different radiative properties and lifetimes. Therefore they have a different warming influence (radiative forcing) on the global climate system. In order to compare the warming influences of all GHGs, a common metric is implemented where the radiative forcing of CO_2 is used as the reference. The equivalent CO_2 emission of a GHG is the amount of CO_2 emission that would cause the same time-integrated radiative forcing, over a given time horizon. This is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) [1].

At the endpoint level, the environmental impact is either expressed in each of the three main categories: damage to human health, damage to ecosystem diversity, and damage to resource availability. The damage to human health is calculated using the concept of disability adjusted life years (DALY). It is based on human health statistics and is the sum of years of life lost and years of life (partially) disabled. It is assumed that every year lost is equal for all ages and possible future damage is disregarded. For ecosystems this method assumes that the diversity of species adequately represents the quality of ecosystems. The indicator that is used is the loss of species during a certain time in a certain area, expressed as the potentially disappeared fraction of species (PDF, in species.year). In this method all species are considered equally important. The indicator is the sum of the effect for terrestrial, freshwater and marine water systems, taking into account the species density. For resource depletion the model is based on the geological distribution of mineral and fossil resources and assesses how the use of these resources causes marginal changes in the efforts to extract future resources (in USD2013). For minerals this means that the average grade of the ore declines. For fossil fuels this means that also less conventional fuels need to be exploited to meet the demands. The basis is the cost increase of extraction due to effects that result from continuous extraction. This is multiplied by a factor that expresses the amount consumed. These three categories are the result of a weighted sum of the ReCiPe midpoint results [3]. An overview of the conversion from data inventory to midpoint and endpoint results is given in Figure 3.

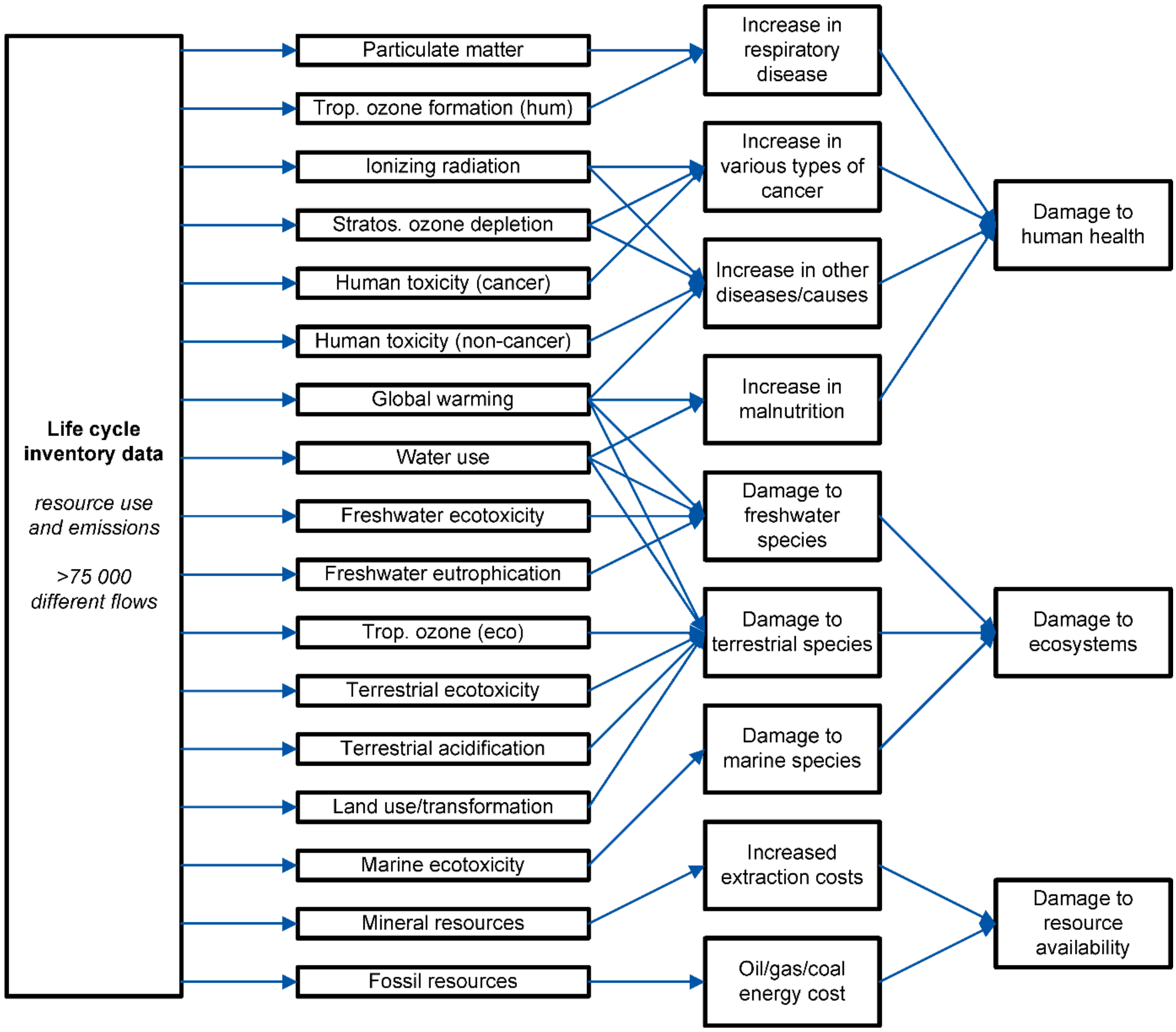

Figure 3: Overview of the ReCiPe method, based on [4]

Economic impact

The economic cost is expressed in euro (2018). As the data used for the economic evaluations are up-to-date, no historic correction is required.

2 Inventory analysis

In this chapter the required inputs and outputs are described for producing, using and wasting both the reference product and the newly developed product. Where possible data were delivered by PEMU. Other data needed were taken from the Ecoinvent 3.4 database.

2.1 Use stage

Before listing the environmental and economic data, an explanation about the use stage of the door panel is provided to clarify the choices made and the calculations performed.

First of all, because the production of the door panel is modelled separately it is not part of the use stage. Secondly, it is assumed a door panel doesn’t need maintenance. Therefore no environmental or economic impact for maintenance was included. This implicates that the use stage of the door panel is only determined by driving the car.

When the dataset for transport with a passenger car of the Ecoinvent database is investigated, most emissions are linked to fuel use and incineration. Only break wear emissions, tyre wear emissions, and road wear emissions aren't linked to fuel consumption. Because the known parameter of the door panel is the mass, a first step in defining a good use stage model for the door panel is determining the relationship between the mass of the car and the fuel consumption. Several studies demonstrate the effect of vehicle weight reduction on fuel consumption. Although the results differ between the different studies, a 10% weight reduction of a car leads to a 3-10% fuel consumption reduction. These results are also valid for a weight increase [5]. For this study it was assumed a weight reduction of 10% leads to a fuel consumption reduction of 7%. The break wear, tyre wear, and road wear emissions are assumed to be fully determined by the mass of the car. This leads to two conclusions. First of all, when the mass of the door panel is reduced, only part of the fuel consumption and the associated environmental impacts will be reduced. This was done by adding a "use factor" equal to 0.7 to the fuel dependent emissions of the Ecoinvent dataset. Secondly, because for the door panel only the mass is taken into account for the use stage, this means that extrapolating the calculated impact of the door panel to the total mass of the car doesn't account for 100% of the impact of the car. This applies to both the environmental and the economic impact. This should be taken into account when comparing the results of this study.

2.2 Environmental data

2.2.1 Reference door panel

For the reference product, Innopol CS 2-9120 was used. This is a talc-filled compound based on polypropylene block-copolymer [6]. The content of this compound is 75.7% polypropylene block copolymer (90% propylene and 10% ethylene), 3% black masterbatch, 20% filler material, and 1.3% other additives [6]. For this study 77% copolymer and no additives was assumed. The total weight of the reference door panel is 1 532 g [7].

For the production stage, injection moulding is used as a process.

For the use stage, data from the European Automobile Manufacturers Association was used. In their report of 2017 the following distribution by fuel type of vehicles in use is given: petrol (55.6%), diesel (41.2%), electric (0.1%), hybrids (0.4%), LPG and natural gas (2.2%), and others (0.4%) [8]. The occurrence of fuel types besides petrol and diesel is very low. There is also not much reliable data about the lifetime of these types of cars because the technology is rather new. Therefore only petrol and diesel cars were taken into account in this study. The other percentages were divided between the petrol and diesel cars. This results in the distribution presented in Table 1. These numbers were used for the calculations. In the Ecoinvent database the average lifetime of any passenger car is 150 000 km. This number is outdated. For the calculations in this study we used more recent data [9], also presented in Table 1.

Table 1: The European passenger cars in use by most important fuel types

Fuel type	Occurrence	Average lifetime
Petrol	57.4%	160 000 km
Diesel	42.6%	208 000 km

For these fuel types the datasets from the Ecoinvent database for the transport with a medium size, Euro 5 passenger car were selected. These datasets assume an average car weight of 1 600 kg. This allows to calculate the distance of the use stage of the door panel for each fuel type with the following equation.

$$[distance\ use\ stage] = \frac{[mass\ door\ panel]}{[mass\ car]} \cdot [average\ lifetime] \cdot [occurrence]$$

As explained before in 2.1, the production of the door panel was modelled separately and it is assumed a door panel of a car doesn't need maintenance. Therefore the selected datasets from the Ecoinvent database were adjusted by removing the production of the car and the maintenance of the car. Also the "use factor" was added to these datasets for all different emissions. The "use factor" was discussed in 2.1 and equals 0.7 for the fuel dependent emissions and 1 for all other emissions.

For the waste treatment the dataset for the waste treatment of PP and PE was used. This dataset takes around 54.2% incineration and 45.8% landfill into account.

The data inventory for the reference door panel is presented in Table 2. The datasets selected from the Ecoinvent database are also mentioned.

Table 2: Data inventory for the reference door panel

Inputs	Amount	Unit
Production door panel		
Polypropylene (PP) *Polypropylene, granulate {RER}| production | APOS, U*	1 062	g
Polyethylene (PE) *Polyethylene, high density, granulate {RER}| production | APOS, U*	118	g
Talc *Clay {RoW}| market for clay | APOS, U*	306	g
Black masterbatch *Carbon black {GLO}| market for | APOS, U*	46	g
Injection moulding process *Injection moulding {RER}| processing | APOS, U*	1 532	g
Use stage		
Transport, petrol car *Transport, passenger car, medium size, petrol, EURO 5 {RER+notprod&main+onlymass}| transport, passenger car, medium size, petrol, EURO 5 | APOS, U*	87.9	km
Transport, diesel car *Transport, passenger car, medium size, diesel, EURO 5 {RER+notprod&main+onlymass}| transport, passenger car, medium size, diesel, EURO 5 | APOS, U*	84.8	km
End-of-life scenario		
Treatment of waste door panel *Waste polyethylene/polypropylene product {Europe without Switzerland}| market for waste polyethylene/polypropylene product | APOS, U*	1 532	g

2.2.2 OptiNanoPro door panel

For the production of the OptiNanoPro door panel the following composition was used: 76% Borealis BH345MO, 15% glass bubbles, 5% black masterbatch, and 4% MBN020_65-Talc-LBM_Wax-Gra [6]. Borealis BH345MO is a heterophasic propylene copolymer having a total ethylene content of 9% [10].

MBN020_65-Talc-LBM_Wax-Gra is a masterbatch based on Talc and PE wax (binder), produced by ball milling. The electricity consumption needed for the production of MBN020_65-Talc-LBM_Wax-Gra was provided by MBN [6, 11]. The exact formulation of this compound is confidential and can be found in deliverable 8.1. The glass bubbles are made of soda-lime borosilicate glass [12]. In Ecoinvent the dataset for borosilicate glass tubes was used because this was the most closely matching dataset available. The total mass of the door panel is 1 301 g [7].

The weight of the OptiNanoPro door panel is 15.1% lower compared to the reference door panel. The distance for the use stage of the OptiNanoPro door panel was calculated using the same equation as for the reference scenario. The mass of the car was adjusted to 1599.769 kg to account for the lower mass of the door panel.

The end-of-life scenario was assumed to be the same as in the reference scenario.

The data inventory for the reference door panel is presented in Table 3. The datasets selected from the Ecoinvent database are also mentioned.

Table 3: Data inventory for the OptiNanoPro door panel

Inputs	Amount	Unit
Production nanoclay		
Talc *Clay {RoW}| market for clay | APOS, U*	*Confidential*	g
PE wax *Polyethylene, high density, granulate {RER}| production | APOS, U*		g
Electricity *Electricity, low voltage {Europe without Switzerland}| market group for | APOS, U*		kWh
Production door panel		
PP *Polypropylene, granulate {RER}| production | APOS, U*	900	g
PE *Polyethylene, high density, granulate {RER}| production | APOS, U*	89	g
Nanoclay	52	g
Black masterbatch *Carbon black {GLO}| market for | APOS, U*	65	g
Glass bubbles *Glass tube, borosilicate {GLO}| market for | APOS, U*	195	g
Injection moulding process *Injection moulding {RER}| processing | APOS, U*	1 301	g
Use stage		
Transport, petrol car *Transport, passenger car, medium size, petrol, EURO 5 {RER+notprod&main+onlymass}| transport, passenger car, medium size, petrol, EURO 5 | APOS, U*	74.7	km
Transport, diesel car *Transport, passenger car, medium size, diesel, EURO 5 {RER+notprod&main+onlymass}| transport, passenger car, medium size, diesel, EURO 5 | APOS, U*	72.1	km
End-of-life scenario		
Treatment of waste door panel *Waste polyethylene/polypropylene product {Europe without Switzerland}| market for waste polyethylene/polypropylene product | APOS, U*	1 301	g

2.3 Economic data

All costs are expressed in euro and are the values in the year 2018.

2.3.1 Reference door panel

The production cost for the door panel was provided by PEMU. For the reference scenario the total cost was 5.10 euro [13].

The costs of owning and driving a car can be found in literature, although the data mentioned in literature can vary a lot. For example, the U.S. Bureau of Labor Statistics calculated that the cost in 2017 for a medium sedan ranges from 47.1 cents to 71.6 cents per mile, where the lower price is when travelling a greater distance [14]. When converting to European standards of 2018, this becomes 0.26 and 0.65 euro per km. For this calculation, 1.61 km for a mile was used, along with the conversion of dollar to euro from 2017 (0.8825) and an inflation of 2.14% [15, 16]. A Belgian consultancy bureau for traffic and mobility uses an average cost of 0.33 euro per km [17]. Dégage, a Belgian car sharing initiative, uses prices between 0.30 and 0.22 euro per km for the use stage of the car [18]. This cost per km however includes the purchase of the car, fuel, maintenance, depreciation, taxes, and insurance. For the costs of the use stage of the door panel in this report no purchase cost must be included because the production cost is calculated separately within the project. It is also difficult to allocate for example taxes to the door panel. Therefore it was chosen to only account for the mass-dependent costs, namely the fuel.

Average fuel consumption data per fuel type for Europe is hard to find. The European Automobile Manufacturers Association estimated the average age of cars in Europe at 10.7 years [8]. The real-world fuel consumption of popular European passenger cars hasn't decreased over the past 10 years and is around 7.2 L/100 km. This is despite a decrease in official fuel efficiency values [19]. Because the real average fuel consumption didn't change over the past years and given the average age of the European cars, this value was used for the calculations. There is however a difference between diesel and petrol cars. This is also reflected in the targets set by the European Commission for 2015 and 2021. In 2015 new cars must have reached a fuel consumption of 5.6 L/100 km for petrol cars and 4.9 L/100 km for diesel cars (official values). The target for 2021 is 4.1 and 3.6 L/100 km, respectively [20]. These numbers suggest a 14% higher fuel consumption for petrol cars. Using this percentage and the distribution of diesel and petrol cars presented in Table 1, the average fuel consumption per fuel type was calculated. The results are presented in Table 4.

To calculate the fuel cost per 100 km, the average European fuel prices of August 2018 were used: 1.47 euro/L for petrol cars and 1.35 euro/L for diesel cars [21]. However, the mass of the car (or the door panel) influences the fuel consumption for only 70%, as was explained with the "use factor" in 2.1. To total fuel cost per 100 km was therefore multiplied with 0.7. The resulting cost in euro per 100 km for the mass dependent fraction of the fuel consumption are presented in Table 4.

Table 4: Average fuel consumption per fuel type

Fuel type	Average fuel consumption (L/100 km)	Average fuel cost (euro/100 km)	Mass-associated average fuel cost (euro/100 km)
Petrol	7.60	11.17	7.82
Diesel	6.66	8.99	6.29

Also the cost of the end-of-life treatment was difficult to determine. No specific cost data about the waste treatment of PP were found. Therefore cost data were estimated using similar materials (plastics), but also in this case the numbers are very different depending on the source. For example a European study gives an example of incineration costs around 70-75 euro/tonne and a landfill cost between 30-100 euro/tonne [22]. American data for high income countries reports costs of 85-200 dollar/tonne for collection, 40-100 dollar/tonne for landfill, and 70-200 dollar/tonne incineration [23]. A Dutch study about the incineration of plastic household waste mentions 6 euro/tonne for collection and 60 euro/tonne for incineration [24]. Another European study about waste treatment of plastics estimated a cost of 140 euro/tonne for landfilling PET. For the incineration of PE, PET and PVC the cost was 196, 98 and 380 euro/tonne, respectively [25]. For this study a incineration cost of 150 euro/tonne and a landfill cost of 100 euro/tonne was taken into account. The dataset for the treatment of waste plastic assumes 54.2% incineration and 45.8% landfilling. This leads to a combined cost of 127.10 euro/tonne for the waste treatment scenario.

The cost for the production, use stage, and end-of-life scenario of the reference scenario are presented in Table 5.

Table 5: Economic data for the reference door panel

Inputs	Cost	Currency
Production of the door panel	5.10	euro
Transport, petrol car	6.87	euro
Transport, diesel car	5.33	euro
Treatment of waste door panel	0.19	euro

2.3.2 OptiNanoPro door panel

The material cost for the OptiNanoPro door panel is 1.10 euro higher because of the use of the nanomaterial.

For the use stage the same approach as with the reference scenario was used. The distances calculated were multiplied with the average fuel costs mentioned in Table 4.

For the waste treatment the calculations performed for the reference scenario were used, where a cost of 127.10 euro/tonne was assumed.

All economic data of the OptiNanoPro door panel can be found in Table 6.

Table 6: Economic data for the OptiNanoPro door panel

Inputs	Cost	Currency
Production of the door panel	6.20	euro
Transport, petrol car	5.84	euro
Transport, diesel car	4.54	euro
Treatment of waste door panel	0.17	euro

3 Impact assessment results

3.1 Environmental results

The carbon footprint and the impact on the ReCiPe endpoint categories were calculated using SimaPro. The results are listed in Table 7.

Table 7: Results of the impact assessment for the reference scenario and the OptiNanoPro product

Method	Amount		Unit
	Reference	OptiNanoPro	
IPCC 2013 GWP 100a	35.81	31.04	kg CO_2 eq.
ReCiPe 2016 – human health	5.41E-5	4.76E-5	DALY
ReCiPe 2016 – ecosystems	1.42E-7	1.24E-7	species.yr
ReCiPe 2016 – resources	5.41	4.65	USD2013

The relative results are presented in Figure 4.

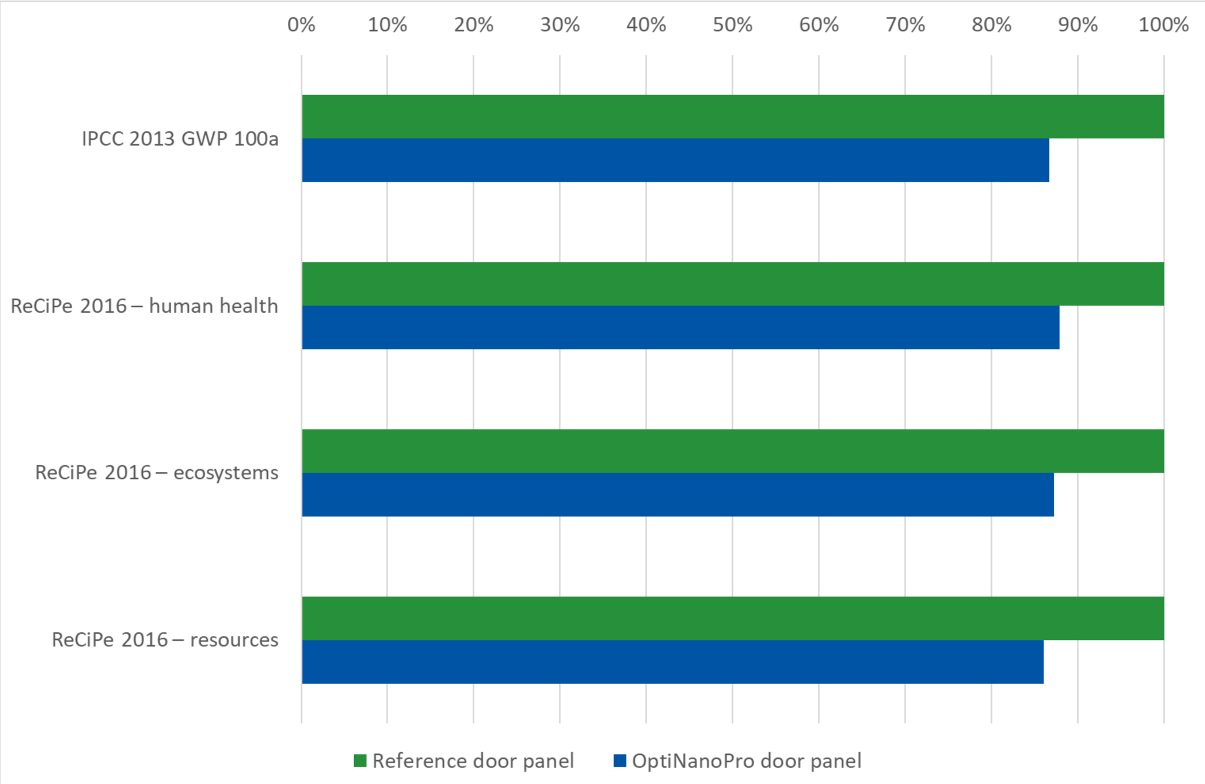

Figure 4: Relative results of the impact assessment for the reference scenario and the OptiNanoPro product

3.2 Economic results

The total costs of both scenarios can be found in Table 8.

Table 8: Total costs of the reference and OptiNanoPro door panel

Scenario	Cost	Currency
Reference door panel	17.49	euro
OptiNanoPro door panel	16.75	euro

3.3 Uncertainty

The uncertainty of the results was measured for all methods taken into account, using Monte Carlo simulations with 1 000 runs and a confidence interval of 95%. The results of the uncertainty assessment are visualised in Figure 5. The uncertainty of the results is quite low.

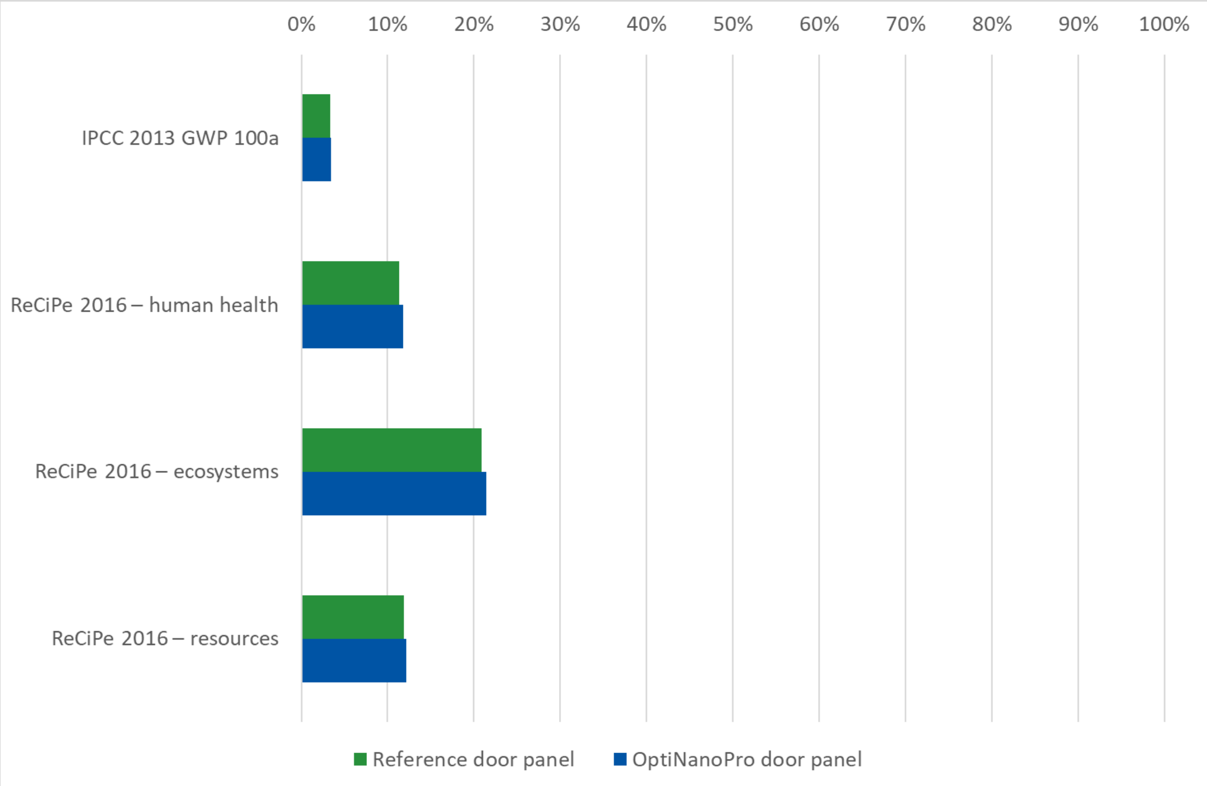

Figure 5: Results of the uncertainty assessment

4 Interpretation and conclusions

In this chapter the results are interpreted and the hotspots of the OptiNanoPro product are discussed. These hotspots represent the most important contributors to the environmental and economic impact. When trying to reduce the impact on the environment or the total cost of the product, the focus should be on these hotspots. Also the comparison with the reference scenario is discussed.

4.1 Environmental impact

4.1.1 Hotspots

The environmental hotspots of the OptiNanoPro door panel are presented in Figure 6. For all methods that have been calculated, the use stage of the product, namely driving with the car (door panel), contributes for around 80% to the total results. The only other flow above 10% of the total environmental impact is the use of PP in terms of resource depletion.

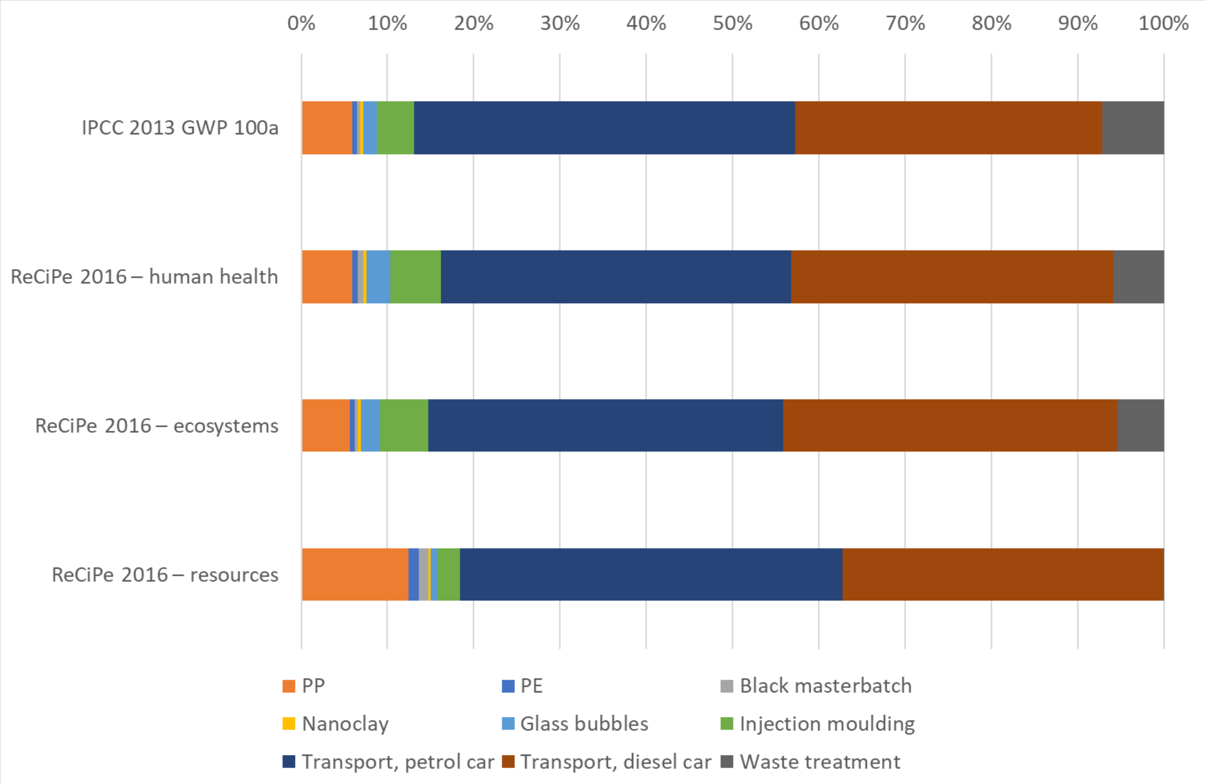

Figure 6: Hotspots of the OptiNanoPro door panel

Climate change

For the carbon footprint almost all of the impact is caused by fossil carbon dioxide emissions. Around 80% of these emissions are caused by the combustion of fuels in the use stage. The remainder is mainly caused by emissions during the production and the end-of-life incineration of PP.

Damage to human health

For damage to human health, the impact is mainly caused by emissions to air of fossil carbon dioxide. Also sulfur dioxide is important, but to a lesser extent. These emissions are mainly associated with the transportation by car, first of all by driving the car but also by the production of the fuel.

Damage to ecosystems

The emission of fossil carbon dioxide is the main cause for the damage to ecosystems. Also the emissions of nitrogen oxides contribute for more than 10% of the impact in this category. Also in this case the transport by car is the most important contributor. Most of the emissions are caused by the combustion of the fuel. Also the production of fuels and the construction of roads contributes to the impact.

Resource depletion

The impact in terms of resource depletion is for around 90% caused by the use of crude oil. This crude oil is linked with petroleum production, mainly used for the production of the car fuels petrol and diesel, but also for the production of PP.

4.1.2 Comparison with the reference scenario

The environmental impact of the OptiNanoPro door panel is around 13% lower in comparison with the reference scenario for all four categories taken into account. This difference is almost entirely caused by the difference in the use stage of the door panel.

To check if the differences are significant a Welch's t-test was performed using the results and the Monte Carlo simulations obtained with SimaPro. The outcome of this test was that the differences are significant for all four categories taken into account.

4.2 Economic impact

4.2.1 Hotspots

The economic hotspots of the OptiNanoPro door panel are presented in Figure 7. The use stage of the door panel accounts for 60% of the total cost. The remainder is mostly because of the production of the door panel.

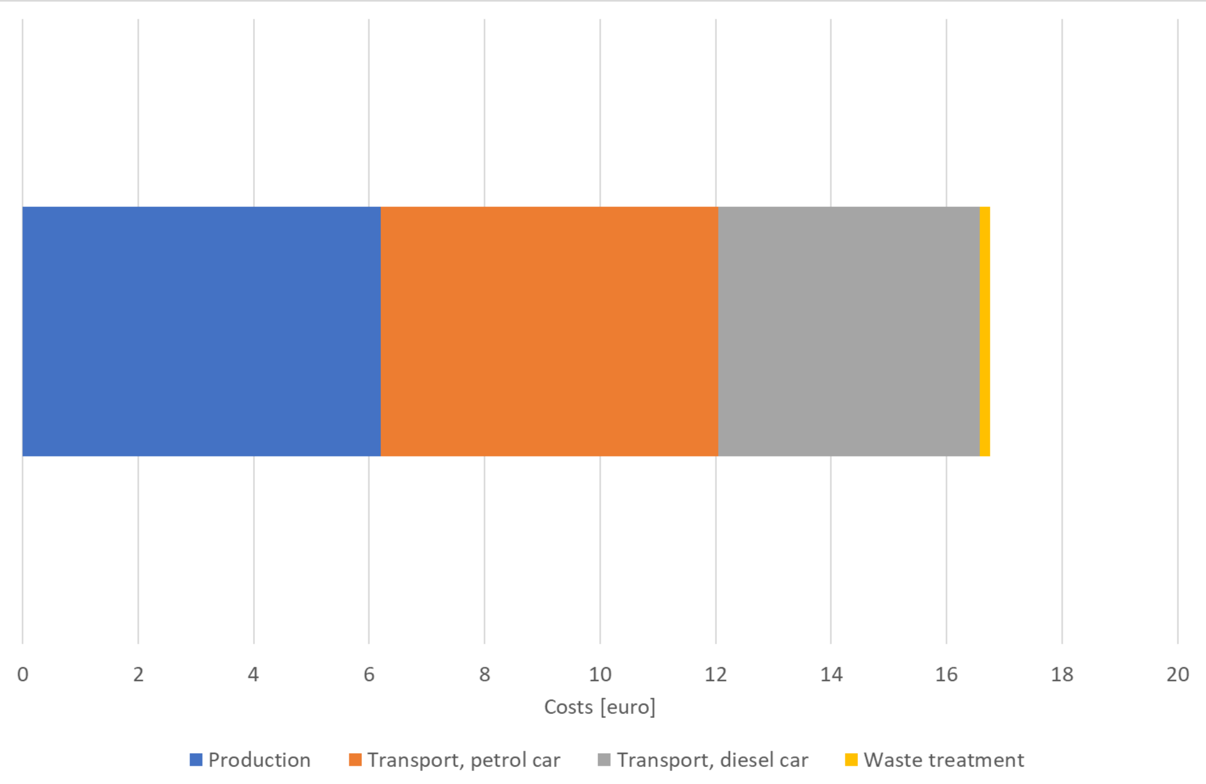

Figure 7: Economic hotspots of the OptiNanoPro door panel

4.2.2 Comparison with the reference scenario

The OptiNanoPro door panel is 0.74 euro less expensive compared to the reference product when taking into account the entire life cycle. The extra production cost (1.10 euro) is mainly compensated by the lower driving costs (use stage) because of the lower mass (around 1.82 euro). The distance of the use stage was defined as the fraction of the total lifetime of a car equal to the mass fraction of the door panel. For the OptiNanoPro door panel this was 74.7 km for petrol and 72.1 km for diesel cars on a total lifetime of 160 000 km and 208 000 km, respectively. Keep in mind that for the cost of the use stage only the mass dependent costs have been taken into account.

4.3 Conclusions

The impact on the environment of the door panel developed within the OptiNanoPro project is lower than that of the reference door panel. For all four impact categories taken into account (IPCC en ReCiPe 2016 endpoint) the impact is around 13% lower. The difference is mainly because of the lower vehicle emissions in the use stage of the OptiNanoPro door panel because of the lower weight.

The environmental footprint for climate change, damage to human health, and damage to ecosystems is mainly caused by fossil carbon dioxide emissions. Most of these emissions originate from the combustion and the production of fuels. For resource depletion, the use of crude oil for petroleum production needed for fuels and PP is the main impact source.

Also from an economic point of view the OptiNanoPro door panel performs better than the reference product when looking at the total life cycle of the product. The extra production costs are compensated by the lower fuel consumption costs caused by the lower weight of the door panel.

The weight reduction of the OptiNanoPro door panel improves the environmental and economic impact. This result is very promising and it can be expected that reducing the weight of other car parts will further improve the total impact of transport with a passenger car. Also the use of recycled PP is expected to further improve the environmental and economic footprint. This was however not calculated due to a lack of reliable data.

Bibliography

[1] European Commission - Joint Research Centre, "International Reference Life Cycle Data System (ILCD) Handbook - Recommandations for Life Cycle Impact Assessment in the European context," Publications Office of the European Union, 2011.

[2] IPCC , "Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change," IPCC, 2007.

[3] M. Goedkoop, R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs and R. Van Zelm, "ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition (version 1.08) Report I: Characterisation," 2013.

[4] Rijksinstituut voor Volksgezondheid en Milieu, "ReCiPe," [Online]. Available: https://www.rivm.nl/en/Topics/L/Life_Cycle_Assessment_LCA/ReCiPe. [Accessed 17 August 2018].

[5] G. Fontaras, N.-G. Zacharof and B. Ciuffo, "Fuel consumption and CO2 emissions from passenger cars in Europe – Laboratory versus real-world emissions," *Progress in Energy and Combustion Science,* vol. 60, pp. 97-131, 2017.

[6] S. Nagy, e-mail communication, 2018.

[7] S. Nagy , "WP8 - Industrial validation of automotive parts," Slides from M30 general meeting, 2018.

[8] European Automobile Manufacturers Association, "ACEA Report - Vehicles in use Europe 2017," 2017.

[9] C. Dun, G. Horton and S. Kollamthodi, "Improvements to the definition of lifetime mileage of light duty vehicles," Report for European Commission - DG Climate Action, 2015.

[10] Borealis AG, "European Patent Application - EP 2 305 751 A1," [Online]. Available: https://patents.google.com/patent/EP2305751A1. [Accessed 04 09 2018].

[11] E. Forlin, e-mail communication, 2018.

[12] 3M, "3M™ Glass Bubbles iM30K," [Online]. Available: http://multimedia.3m.com/mws/media/625127O/3m-glass-bubbles-im30k.pdf. [Accessed 04 09 2018].

[13] S. Nagy, U. Bölz, E. Forlin and L. Six, "WP8 Industrial validation of automotive parts," Slides from M36 general meeting, 2018.

[14] L. Smith, "The True Cost Of Owning A Car," 18 11 2017. [Online]. Available: https://www.investopedia.com/articles/pf/08/cost-car-ownership.asp. [Accessed 18 09 2018].

[15] "Gemiddelde referentiewisselkoersen in euro voor het jaar 2017," Lexalert, 19 02 2018. [Online]. Available: http://www.lexalert.be/nl/article/gemiddelde-referentiewisselkoersen-euro-voor-het-jaar-2017. [Accessed 25 09 2018].

[16] "Inflatie Europa Eurozone - HICP," Home Finance, [Online]. Available: https://www.homefinance.nl/economie/inflatie/inflatie-europa-eurozone-hicp.asp. [Accessed 25 09 2018].

[17] "Zoveel kost je auto écht," Radio 2, 25 10 2017. [Online]. Available: https://radio2.be/de-inspecteur/zoveel-kost-je-auto-echt. [Accessed 18 09 2018].

[18] "De kilometerprijs," Dégage, [Online]. Available: https://www.degage.be/autodelen/de-prijzen/. [Accessed 25 09 2018].

[19] U. Tietge, P. Mock, N. Zacharof and V. Franco, "Real-world fuel consumption of popular European passenger car models," The International Council on Clean Transportation, 2015.

[20] "Reducing CO2 emissions from passenger cars," European Commission, [Online]. Available: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en. [Accessed 21 09 2018].

[21] "Fuel price calculator: How much do you pay?," BBC, 29 08 2018. [Online]. Available: https://www.bbc.com/news/business-21238363. [Accessed 26 09 2018].

[22] D. Hogg, "Costs for Municipal Waste Management in the EU," Eunomia Research & Consulting.

[23] "Estimated Solid Waste Management Costs," Urban Development Series – Knowledge Papers, [Online]. Available: http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/AnnexE.pdf. [Accessed 12 09 2018].

[24] R. H. Gradus, P. H. Nillesen, E. Dijkgraaf and R. J. van Koppen, "A Cost-effectiveness Analysis for Incineration or Recycling of Dutch Household Plastic Waste," *Ecological Economics,* vol. 135, pp. 22-28, 2017.

[25] "Evaluation of costs and benefits for the achievement of reuse and recycling targets for the different packaging materials in the frame of the packaging and packaging waste directive 94/62/EC," RDC-Environment & Pira International, 2003.