



The use phase in the aluminium mass flow – An approach for integration

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Abstract

In mass flow analyses the use phase is often not adequately integrated. Above all user-related effects, life-time of products or product-systems are frequently unconsidered. Looking at the entire process chain the total demand for aluminum is important. But balancing the environmental impacts of the use phase of aluminum-bearing products such as cars, trains, window frames, or beverage cans three other targets win importance. These are the identification of environmental impacts during the use phase itself and its integration in the process chain. Using this data the third target aims at case studies which point out various user-related effects.

For this purpose mass flows and induced environmental impacts of the particular product use, startup, maintenance and repair have to be quantified separately using LCA. For this targets the consideration of the multifunctional material properties is important which requires the choice of a suitable functional unit in order to reproduce all parameters. Furthermore, those mass flows have to be considered which are influenced by the user. Besides socio-economic factors the individual user behavior is determined by exogenous parameters such as distribution and availability of product information. Additionally, it is important to include the life-time of products, because the effects can only be shown after a certain time of usage or, due to the high life time of some products, by summation. On the basis of examples from the aluminum sector particular spectra of the usage are represented with focus either on user behavior, technological potential, recycling ability or life span.

1 Introduction

The process chain of aluminium production is described by the several studies of the Collaborative Research Center (CRC) 525 "Resource-orientated analysis of metallic raw material flows" described but the use phase was excluded up to now. The purpose of this study is on one hand to close the gap and on the other hand to develop a method for integration the use phase in the mass flow. Aluminium is well suited for many uses because of its properties and processing methods. The total demand of aluminium in Germany, which amounts to 2.7 mio. Tonnes (2001), is shared into eight consumer sectors (see figure 1 (left)). It can be calculated that that about 10 % (285000 tonnes) is covered by the automobile industrie (3.341 mio. newly admitted vehicles). In these sectors aluminium is bounded in depots during the usephase. According to the lifespan of the different product components, products respectivley product systems it is estimated that this amount sums up to approx. 700 mio. Tonnes (2001).

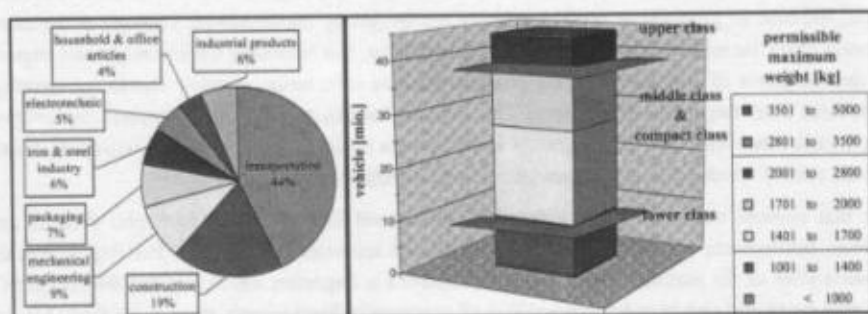


Figure 1: Distribution of the aluminium consumption to the industry sectors in Germany (2001)[1] (left) and rolling stock per permissible maximum weight [2](right)

The largest end-consumer market for aluminium has been the transportation sector already over a long period. About 44 % of the aluminium produced is captured here. Originally essential for light-weight applications in the aerospace industry, aluminium is now widely used in bicycles, cars, buses, coaches, lorries, trains, ships, ferries, and aircrafts.

The use of aluminium in vehicles rised continuously in the last years. Presently the average aluminium mass is approximately 80 kg per vehicle in Europe. The European Aluminium Association (EAA) estimates that this value will increase to approximately 160 kg per vehicle in the year 2008 (see figure 2). Several aluminium applications are already established in functional units like engine, drive train, and chassis (see table 1). While in the past aluminium is widely used in upper-class cars, at the present time car manufacturers became more interested for aluminium applications of the middle and compact class in order to reduce the car weight or at least to compensate the weight of new features in the cars.

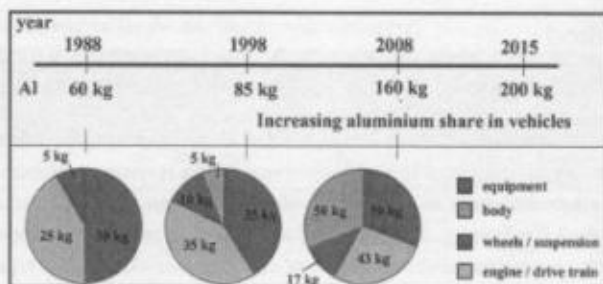


Figure 2: Aluminium use in car-components (estimated)[1][3][11][12]

In this report an analysis will be carried out on the environmental impacts which are connected with the use in individual traffic applications due to its lightweight potential in present and future vehicles. As a basis for the analysis a “state-of-the-art aluminium vehicle” (SAV) with 80 kg (2002) as the current average aluminium weight in vehicles is defined as a reference-car (2000). In a second step an estimation is made of the future average use of aluminium of 160 kg per vehicle (2008), respectively of 210 kg per vehicle (2015), whereas these vehicles are called “aluminium-intensive-vehicle” (AIV) respectively “aluminium-maximised vehicle” (AMV). This study covers the environmental impacts of primary weight savings as well as the potential for the so called secondary weight savings. A second view is given to the impact of the resource requirements of individual use types (driving styles) compared with a “standard” consumer behaviour, which may superimpose any light-weight-advantage of Aluminium.

Table 1: Application of aluminium alloys (examples)

	Alloy	Application	
Wrought alloy	AlCuMg 2	<ul style="list-style-type: none"> • wheel bearing • transverse control arm 	<ul style="list-style-type: none"> • crank and camshaft
	AlMgSi 1	<ul style="list-style-type: none"> • wheels 	<ul style="list-style-type: none"> • profiles for the structure
	AlMg 2	<ul style="list-style-type: none"> • sheets for the car body 	
	AlSi 17 CuNi	<ul style="list-style-type: none"> • piston (pressed) 	
Casted alloy	G-AlSi 12	<ul style="list-style-type: none"> • crank case • oil pan 	<ul style="list-style-type: none"> • gear case
	G-AlSi 10 Mg	<ul style="list-style-type: none"> • crank case 	<ul style="list-style-type: none"> • cylinder head (watercooled)
	GK-AlSi 12 CuNi	<ul style="list-style-type: none"> • casted piston 	
	AlSi9Cu4	<ul style="list-style-type: none"> • general applicable 	

2 Method

2.1 The integration of the use phase in the Aluminium mass flow

In order to reduce the environmental impacts of product components, products or a service as efficiently and effectively as possible, it is necessary to analyse the resource requirements (e.g. energy consumption) of all process steps in of a "closed loop"- view from production to the disposal. For this a balance method is necessary, which seizes mass as well as energetic in- and outputs in an inventory. Throughout the requirements of mass- and energy preservation in the regarded system the completeness of the balance in the sense of an Holistic view has to be examined (see figure 3).



Figure 3: Life cycle of Aluminium

The inventory can be designed as a matrix, whereby the regarded processes along the life span are described in a vertical analysis and the categories of the in- and outputs of the respective subprocesses are described in a horizontal analysis. In this paper the subprocess "use phase" is investigated (see table 2).

Different investigations [6,7,8, 9] postulate that in the entire life cycle of a product the use phase has the highest environmental relevance so that a detailed view of the use phase is necessary. In our model the use phase consists of five subphases (see figure 4), which have different relevance and intensity depending upon product. Generally the use of a product begins with the distribution to the final consumer (private or commercial consumer, service) and/or with its purchase and ends with the operation shut down and supply to the recycling cycle (collecting, sorting, processing) respectively to the waste utilization plant.

Table 2: Analysis matrix for the use phase (with examples)

	purchase	operation startup	use	maintenance - repair	operation shut-down
status of vehicle	for selling	in state of transportation	in state of going into operation	in state of service repaired	in defect state
input	Not investigated	detergents	fuel, oil, water	water, oil, battery, wheel, coolant	fuel
output		emissions, packaging cleaning thinks	emissions	water, oil, battery, wheel tools	registration
working material					tools
user profile			commuter, housewife	car owner engineer	
process management			commuter traffic weekend traffic		transportation to the graveyard
process surrounding			high way, motorway, country road	garage	auto graveyard

The subphase "purchase" is determined primarily by more or less conservative, conscious acting of the buyer. This requires sense of responsibility, innovation strength and competence from both the buyer and the seller regarding ecological and socio-economic technique consequences and to avoid emissions. The "operation startup" of products can not be generalized. The start-up of a vehicle covers the filling with fuel, the removing from protection material and the inserting of additional equipments. This is quite different to other Aluminium applications as the start-up of a packing or can covers the packaging or filling, the distribution and the storage in the wholesale respectively supermarket. The subphase "use" of a product represents the operational conditioning and the actual use of the product. This covers the application and consumption of products, the operation of a vehicle or a machine as well as the manufacturing of other products with the aluminium product.. The use of a product can be again subdivided into the phases preparation, use and aftertreatment. The maintenance of products takes place to a great extent according to fixed schemes. Here measures are carried out for keeping the function of the product in good condition. Repair measures are often not planned events, which are differently complex. In the subphase "operation shut down" the product is supplied accordingly to waste disposal decrees to waste utilization plants for paper, glass, plastics and to the recycling systems mainly for metals.

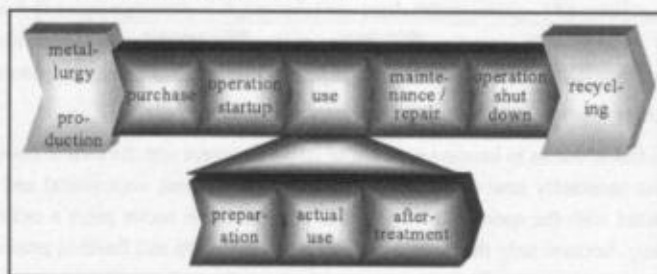


Figure 4: The use phase, divided into five sections, in the mass flow

2.2 Life-cycle-balances tool: GaBi

The software system GaBi [4] is a commercial tool to build up mass flow and life-cycle-balances. Its calculation possibilities are limited to product life cycle analysis but GaBi illustrates quite good the life cycle in flow charts respectively in Sankey diagrams, allowing a quick overview of mass, energy or even financial requirements. Some data is already contained in GaBi data bases and can be easily expanded and changed using the powerful datasource of the collaborative research center SFB525 in Aachen [10]. From the calculated mass flow analyses the results can be transferred to build ecobalances, which represents a combination of inventory and assessment. For the evaluation using the "GaBi-analyst", variations of the parameter and scenario analyses have to be carried out. Thus the ecological effects (greenhouse effect etc.) and its changes due to different assumptions like SAV, AIV and AMV can be determined.

3 The future of the passenger vehicle as means of transport?

This question the pioneers of the passenger cars asked themselves such as Ford and Benz in the end of the 18th century. Hardly any product in our daily use, affected in such a manner the entire society over several generations in thinking, acting and planning. While the automobile became technically perfect, more comfortably as well as affordable for almost everyone, the economical, social and ecological problems will grow with the use of the automobile (world-wide 500 millions in the year 2001) (data for Germany see figure 5).

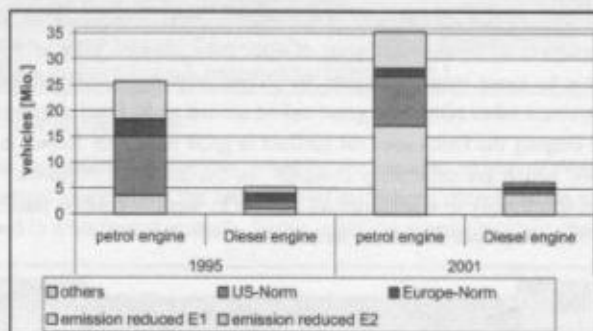


Figure 5: Rolling stock of emission-reduced vehicles in Germany [2]

The individual traffic seems to become a victim of its own success and the further rising demand for mobility creates constantly new challenges, because still the social, economical and cultural progress is connected with the speed of mobility. The transportation sector plays a central role in the modern economy, because only the mobility of raw materials, semi and finished products as well as people (e.g. pupils, trainees, working persons, travelers, consumers) ensures the share of labour and welfare in all sectors of the economy. In the background of the globalization the traffic sector be-

comes a constantly growing significance. Resource-requirements, land consumption and environmental pollutions induced by traffic as well as direct and indirect damage of humans and nature (e.g. by accidents) require a reorientation in production and recycling of vehicles. This is also in respect to traffic space and traffic management as well as driver training. In the last decades the weight of the vehicles increased continuously (see figure 2 and 6). Safety measures, emission reduction measures, and claims for more comfort led directly and indirectly through adjustment of engine and chassis to an increasing weight of 1,600 kg of present vehicles in the previous 40 years.

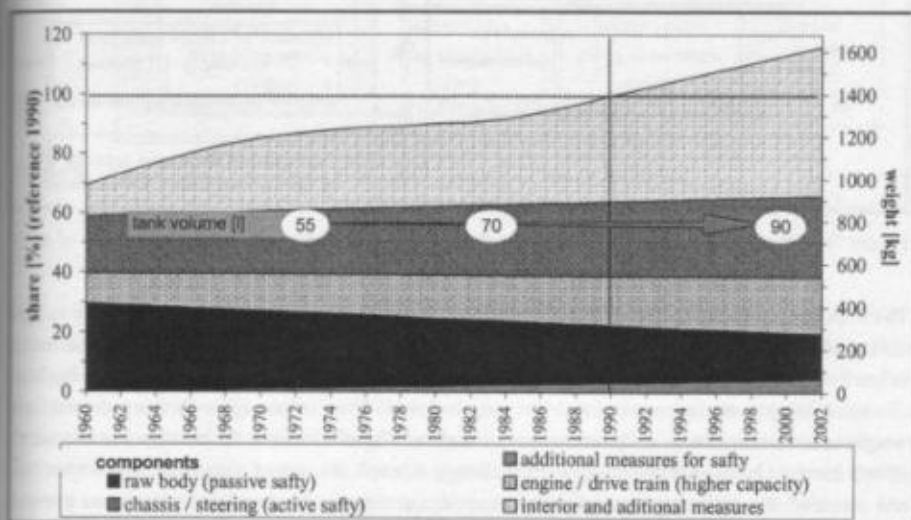


Figure 6: Development of the weight of an mid-class vehicle [4, modified]

3.1 Benefit and Potential of Weight Savings Using Aluminium in Cars

With the movement of the vehicle various driving resistances (the movement against work), which determine the fuel consumption as a function of the mass substantially. The total traction resistance F_w of a vehicle results from the sum of rolling resistance F_{R0} , ascent resistance F_L , flow resistance and acceleration resistance F_A , whereby the single resistances operate not all at the same time (see figure 7 left).

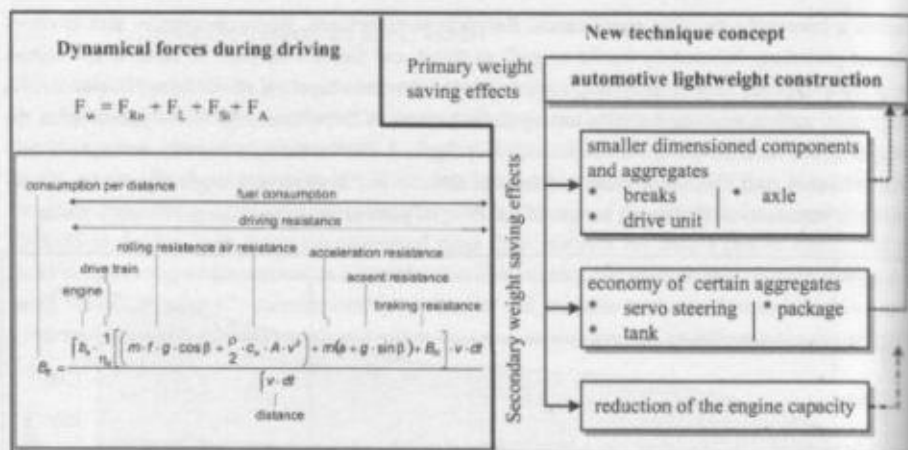


Figure 7: Dynamical forces during driving (left) [3] and primary and secondary effects of automotive lightweight construction (right) [3][12]

The importance of the vehicle weight for a reduced fuel consumption is undisputed. Primary weight saving effects can be obtained through weight reduction of the body. The success of such measures is basis for further savings at other vehicle components. The light weight construction leads to downsized aggregates and components like engine or tank. They induce again further potential light weight construction, the so called secundoray weight saving effects. Both the primary and secondary effects have to be considered when weight savings through the use of aluminium are determined and assessed. By replacing more components with current or new developed aluminium components a primary weight saving is realized. To determine the secondary weight saving the impact of this measure on the weight of the motor, chassis, body and drive-train have to be cosideres, as they can reduced by downscaling according to the new technique concept (see figure 7, right). For future vehicle generations the target for weight reduction is 30 - 35 %, which is equivalent to approx. 300 - 450 kg for a midclass vehicle. (see figure 8)[5].

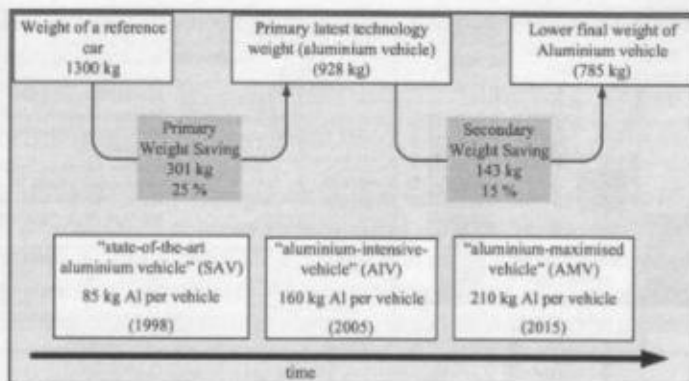


Figure 8: Targeted weight saving in the next car generations [4, modified]

4 Environmental Impact of the User Behaviour

Following the rule "To succeed in an one-litre-vehicle it is nessecarry to have an one-litre-driver", the behaviour of the car drivers has to be taken in account. Motor vehicles are subject to various EEC-guidelines, where the requirements regarding active and passive vehicle safety as well as fuel consumption and thus CO₂-emissions of a vehicle are regulated. Consequently the definition of a "normal consumption" of a vehicle is vehicle specific and varies upon the class. Fuel can be saved not only with a low-consumption car, but also significantly with a foresighted and reserved driving method and last not bus least with a regularly maintained car. Driver trainings give helpful tips:

- "30-liter-vehicle"? – by frequent cold startings
- 1.5 - 2.7 % fuel saving with light oils
- aircondition is costly: approx. 0.3 - 0.7 l per hour
- power generation (e.g. music, navigation system) needs fuel: 0.5 l/100 km (average value)
- when the vehicle stops for more than 60 seconds - engine out
- drive in high gears / low rpm-values
- keep to the recommended speed on motorways

Almost each use of products leads to environmental impacts by the interaction "user – product – environment". The user and his use behavior attain thereby special attention, because the extend of the environmental impact is directly dependent on the use behavior. The environmental impact of a use phase consists of user independend, so called technology-determined, individual and social determined effects (see figure 9, left).

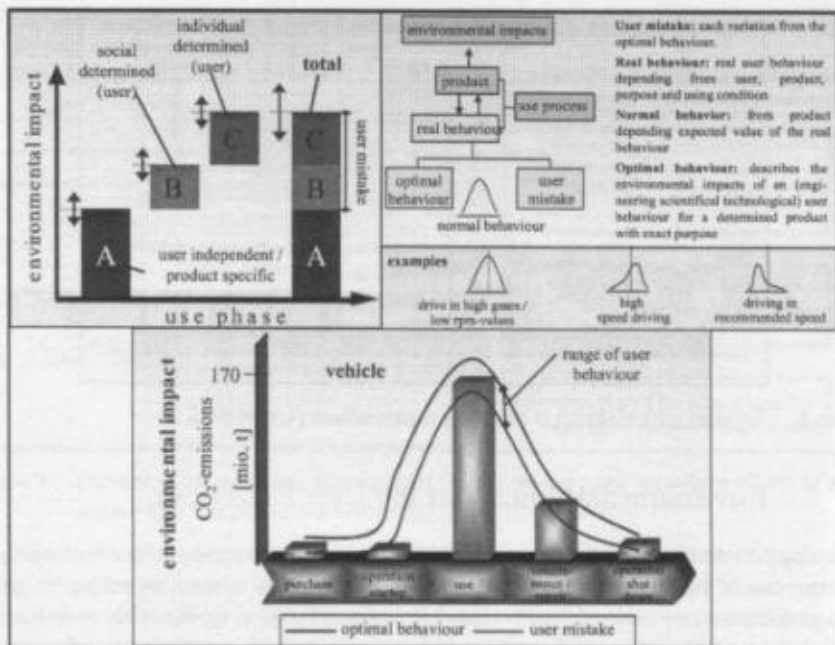


Figure 9: Classification of environmental impact sources (left), description of the user behaviour (right), and influence of the user behaviour (own calculation)(down)

The technology-determined environmental impacts are product intrinsic, which means that the user has no influence. Neglecting the influence of any user behavior this would be the expectable environmental effect from the outgoing product and thus represents the optimal behavior. The individual-determined impacts depends directly on the user behavior, since these are affected by various factors such as motivation, environmental interest, time and budget as well as by the social surrounding. The surplus of environmental impacts as a function of the number of persons in the vehicle can be related to social-determined effects, compared with the purpose to use a vehicle with full capacity. Individual-determined impacts results for e.g. from high speed or high accelerating drivers.

The "normal behavior" of an user is located somewhere between optimal behaviour and lapse depending on what kind of preference the user has regarding time, budget, or environmental interest (see figure 9 (right)). Altogether the consumer-dependent use behaviour always lead to failures, which are oftentimes multilayered.

In figure 9 (down) the CO₂-emissions is distributed to the individual subphases. The purchase phase is estimated because in this study this subphase is deeply investigated. The columns correspond to

the environmental impacts, calculated with GaBi which vary upon the above described factors as well as climatic or regional parameters.

5 Results and Assessment

The environmental impact of the vehicle use phase is significant and the reasons are manifold and many parameters have to be considered simultaneously. Using a "spider chart" it is possible to illustrate qualitative as well as quantitative results and to give a summarized assessment of the use phase at the same time. The center of the cobwebs represents the optimum of all parameters, the outer edge of the cobweb stands for the worst case. The scale is linear in order to provide distortions.

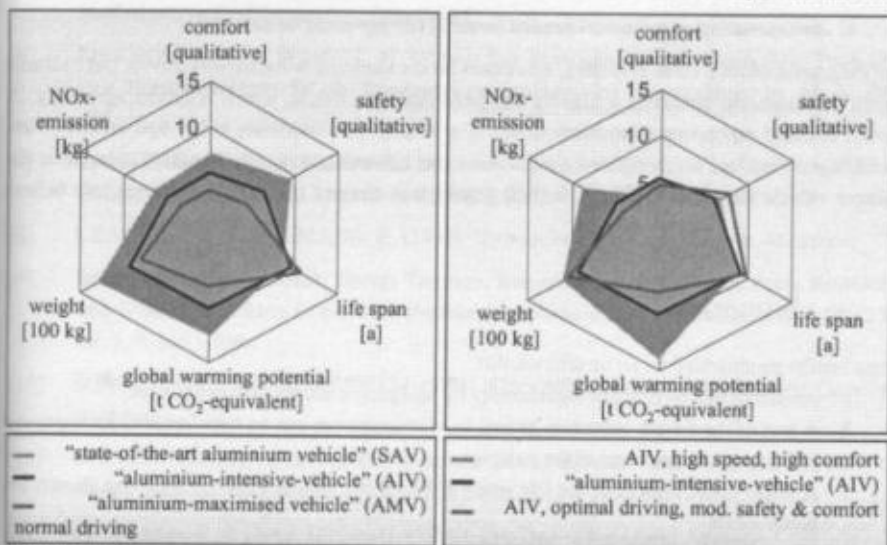


Figure 10: Environmental impact (left) and user influence (right) of the use phase of a aluminium vehicle (calculated)

Figure 10 (left) shows the GaBi calculated emission results of the three technologies using different shares of aluminium (SAV, AIV, AMV) together with improvements in safety, comfort, weight and life span. In view of the vehicle (user independent factors) the consumption of fuel can be reduced significant with which a reduction of emissions is obtained. For every 100 kg reduction of the weight, there is a decrease of 0.3 to 0.6 litres per 100 km in fuel consumption accompanied with a reduction of gas emissions up to 20% [3]. As shown in the spider chart the emissions of CO₂ and NO_x are obviously lower for the aluminium-intensive-vehicles (AIV) and aluminium-maximised-vehicles (AMV) than for the state-of-the-art aluminium vehicle (SAV). Even safety improvements

and life span extending measures can be realized without increasing emissions. Furthermore aluminium in vehicles increases safety directly through the new body concept or increasing energy absorbency during crash. Through the mass reduction there is the possibility to add more safety components without exceeding the actual car weight (indirect effect).

The big share of drivers with non-optimal user behaviour lead to considerable environmental impacts. The user does have influence on fuel consumption on four levels (see figure 10):

1. selection of vehicle type (consumption, safety, extras,...)
2. driving reason and "being lazy" (especially: short distances)
3. driving style (speed, foresighted,...)
4. transporting of not actual needed material (empty waetr bottles,...)

The diagramm reflects three scenarios, als based on the aluminium-intensive-vehivcle (AIV) (basis 2008). One scenario combines a highly equipped (heavy) vehicle, which is driven aggressively. A second scenario represents a moderate driver in a vehicle with moderate safety and comfort standard (no seat-heating, no navigation system, no extra hifi-equipment,...). The third scenario is the referece vehicle also used in figure 10 (left) (blue lines) equiped standard, but normal user behaviour.

6 Summary

These results summarized it can be schown that

1. emissions can be reduced significantly by using more aluminium in vehicles
2. A part of the weight reduction gained by aluminium use can be transferred to an improved safety and comfort level of the vehicles.
3. A slight improvement of the life span of the vehicle can be obtained by using aluminium components.
4. The user behaviour influences the emissions significantly. A high-speed driver compensates the advantages of an aluminium use by far.

7 Literature

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