Complete Life Cycle Assessment for Vehicle Models of the Mobility CarSharing Fleet Switzerland

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Abstract

Mobility Car Sharing Switzerland has developed a new, extended Life Cycle Assessment tool to assess the complete environmental burden of their car models. Life Cycle Assessment (LCA), encompasses burdens from resource extraction, to car manufacture, use and disposal. To get an impression of the relative magnitude of the total environmental burden caused by different aspects of today's car models, not only exhaust emissions, fuel consumption and material use for car and road infrastructure was heeded, but also health damages from road noise and motor vehicle accidents, environmental burdens from land use and landscape fragmentation were included in the assessment. The aim is to develop a comprehensive indicator expressing the environmental load of car models per vehicle kilometer. For this purpose a new valuation method – MUPB'97 – was devised, which aggregates all burdens mentioned above into a single value (Doka 2000) The MUPB'97 method is a consistent extension of the well-known and broadly applied BUWAL method of ecological scarcity aka Umweltbelastungspunkte, UBP'97 (Brand et al. 1998) and is based on established political or societal goals regarding environmental problems in Switzerland.

Compared with a current average Swiss passenger car, the car models of Mobility CarSharing Switzerland show up to 39% reduced overall environmental burden as expressed in MUBP'97-points per vehicle kilometer. The best car models were found to be small limousines like VW Lupo TDI 3l, Smart and Opel Corsa. However, a minority of the car models have roughly equal than average impacts. These car models are transporters and large passenger vehicles for up to 8 passengers. The results will be used in the future for environmental reporting by Mobility and will help Mobility fleet managers to promote a environmentally optimized acquisition of new cars.

The analysis also shows that for Mobility CarSharing cars regulated exhaust emissions like NO_x, HC, CO and PM10 particles are at a very low level. Compared to these emissions, other burdens like health damages from noise and accidents, fuel manufacture and CO_2 exhaust emissions are more relevant for the environment. Hence for *modern* cars, the regulated exhaust emissions can be considered to be of little importance in the overall environmental burden of the car. From this point of view, measures to reduce other burdens such as road noise, accident casualties and fuel manufacture, promise to be more effective for modern cars. Also land use aspects (road infrastructure, landscape fragmentation) and material consumption aspects (car manufacture, servicing and disposal) are increasingly significant, and, for low burdening cars can become more important than fuel-related issues.

Keywords

Mobility – car sharing – Life Cycle Assessment – LCA – total environmental impact – noise – accidents – land use – landscape fragmentation – ecological scarcity – UBP – MUBP – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Car Sharing Switzerland

1.1 An Introduction

Mobility CarSharing Switzerland is the largest car sharing organisation in the world and services 40% of the whole car sharing customer community worldwide. Car sharing activities in Switzerland have a history of 12 years and have been stimulated by two cooperatives. 1997 saw the merger of these cooperatives into one nationwide provider 'Mobility CarSharing Switzerland'. Since then the growth rates have been in a take off phase of 30 – 50 % regarding customer and vehicle figures. At present Mobility CarSharing Switzerland has 1450 vehicles on the road, which are being shared by 40'000 customers and 800 businesses with a total of 5'500 employees using a shared car. Mobility CarSharing works in close collaboration with regional public transport (combined tickets with 13 tarification nets and the national railway system SBB AG).

1.2 Use of transport means by Mobility members

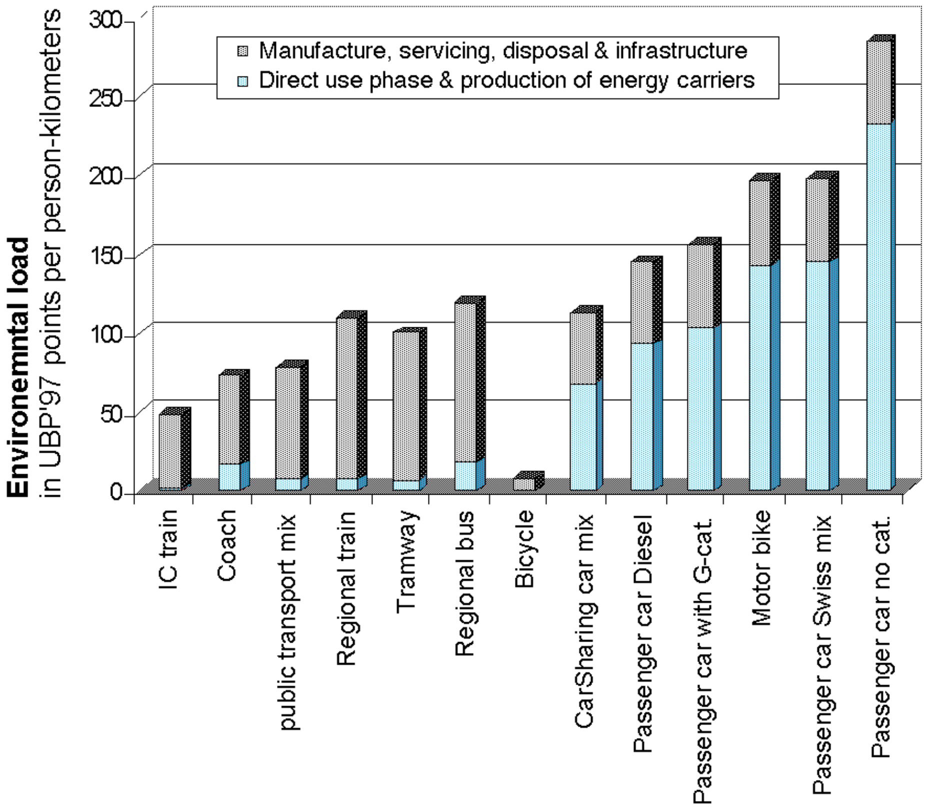
Car sharers are confirmed mobility combiners: they prefer a mixture of transportation means apart from the car. Figure 1 shows how after six months of membership the average car sharer has changed his/her transportation habits. With this change in transportation habits a drastic modal split change follow. According to Table 1 from the scientific survey (Muheim 1998) a car sharer uses a car only 20% of the time and prefers taking other means of transport 80% of the time. This entails a significant reduction in the environmental load, as can be seen in Figure 1 (Mertens 2000).

Table 1 Use of transport means with and without a car sharing membership

Active Users	Transport means	100 % Car users
34.6 %	rail / postalbus	9.1 %
20.1 %	bicycle	8.0 %
17.4 %	bus / tramway	9.6 %
8.1 %	by foot	11.4 %
6.2 %	CarSharing-Car	-
5.4 %	second vehicle	53.8 %
2.9 %	motorcycle	1.6 %
1.8 %	companycar	4.4 %
1.5 %	friends car	0.7 %
0.6 %	car rental	-
0.5 %	scooter	1.0 %
0.2 %	taxi	-

Source: Muheim (1998)

Figure 1 Grey and direct environmental burdens of car sharing cars compared to other means of transport.

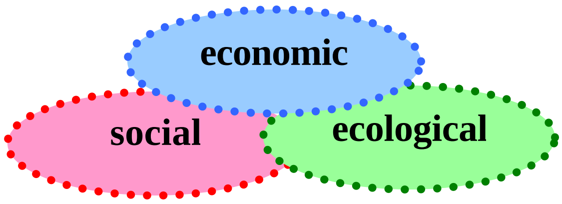


Source: Mertens (2000)

1.3 The 3–S Strategy of Mobility CarSharing Switzerland

The behavioural changes above may be labelled the lifestyle component of the ecological component of corporate responsibility. Mobility CarSharing Switzerland defines itself as a company with a responsibility covering social and ecological aspects. Only with a transparent track record in these fields, a long-term economic sustainability can be archived. The principle of 3–S strategy (sustainable services and systems) has proven to be key motivators in the economy as such, especially in the service systems context (Meijkamp, 2000). Since Mobility CarSharing is a cooperative the revenue must be reinvested and there is a shift from a mere shareholder viewpoint to a higher more holistic viewpoint of including 3–S strategies. However the cooperative members have to decide on these strategic goals. A user/member decides thus between low tariffs (for perhaps vehicles emitting more pollutants) and individual corporate responsibility (reinvesting revenue on environmental measures as a value). Still Mobility CarSharing Switzerland sees itself in the early business cycle stage of a pioneer company with goals such as service quality, network growth and vehicle reservation probability as a priority target. On the other hand Mobility owns the greater part of its fleet and needs criteria of buying and selling, which may be subordinate to the pure ecological criteria of the vehicles owned. Thus the clients are pulled into a broader sense of responsibility than a sole service user.

Figure 2 Three levels of responsibility.



1.4 Motives for a new method in fleet management

Environmentally conscious car fleet managers need comprehensive tools to choose environmentally well-performing car models. Up until now only coarse partial indicators like fuel consumption per kilometer, or EURO exhaust emission categories have been applied, which only cover a part of the environmental performance of a car. Consumer transport associations such as VCD/VCS-ATE provide lists with environmental scores for different car models (Egli et al. 2000). These lists are based on an ad hoc methodology focussing on the use phase impacts of vehicles. This study devises a method which tries to assess all enviornmental burdens from the complete life cycle of a car.

2. The Mobility Life Cycle Assessment

2.1 Methods

Mobility CarSharing Switzerland commissioned a study analysing the total life cycle of the vehicle models in their current fleet. The Life Cycle Assessment (LCA), encompasses burdens from resource extraction, to car manufacture, use and finally its disposal. To get an impression of the relative magnitude of the environmental burdens caused by different aspects of today's car models, not only exhaust emissions, fuel consumption and material use for car and road infrastructure was heeded, but also health damages from road noise and motor vehicle accidents, environmental burdens from land use and landscape fragmentation were included in the assessment.

The aim is to develop a comprehensive indicator expressing the complete environmental load of car models per vehicle kilometer. For this purpose a new valuation method – MUPB'97 – was devised, which aggregates all burdens mentioned above into a single value (Doka 2000). The MUPB'97 method is a consistent extension of the well-known and broadly applied BUWAL method of ecological scarcity; also known as Umweltbelastungspunkte or UBP'97 (Brand et al. 1998) and is likewise based on established political or societal goals regarding environmental problems in Switzerland.

Table 2 Environmental effects heeded in the MUBP'97 valuation method.

Category	Environmental effects (examples)	New in MUBP'97
Pollutants	Global warming (CO_2, CH_4, N_2O...)	
	Summer smog (VOC, NO_x)	
	Acidification (SO_x...)	
	Eutrophication (PO_4, NH_3...)	
	Ozone depleters (CFCs, HCFCs...)	
	Heavy metals (lead, zinc, cadmium...)	
	Carbon monoxide CO	New
Resources	Energy raw materials (oil, uranium...)	
	Disposal sites (various wastes)	
	Land use	New
	Landscape fragmentation	New
Other health impacts	Road traffic noise	New
	Fatalities from road accidents	New
	Injuries from road accidents	New

23 car models in the current Mobility fleet were analysed in depth. For reasons of comparison, a statistical average of a current Swiss passenger car model was assessed as well. The results are calculated for a total life time service of 150'000 vehicle-kilometers (= functional unit).

2.2 Mobility CarSharing fleet performance - Results

2.2.1 A summary

Compared with an average Swiss passenger car in 1999, the car models of Mobility CarSharing Switzerland show up to 39% reduced overall burden as expressed in MUBP'97-points per vehicle kilometer. The best car models were found to be small limousines like VW Lupo TDI 3l, Opel Corsa and Smart. However, a minority of the car models have roughly equal impacts than the Swiss average. These car models are vans, transporters and large passenger vehicles for up to 8 passengers. The results will help Mobility fleet managers to promote a environmentally optimised acquisition of new cars. They will also be used in the future for yearly environmental reporting by Mobility.

2.2.2 A new focus is needed due to developments in vehicle design

The analysis also shows that for Mobility CarSharing cars regulated exhaust emissions like NO_x, HC, CO and PM10 particles are at a very low level. Compared to these emissions, other burdens like health damages from noise and accidents, fuel manufacture and CO_2 exhaust emissions are more relevant for the environment. Hence for *modern* cars, the regulated exhaust emissions can be considered to be of little importance in the overall environmental burden of the car. This result can be confirmed with other impact valuation methods such as Eco-indicator95+ (Jungbluth 2000) and is therefore not an artefact of the MUBP'97 valuation method. The results signifies that past efforts to reduce exhaust emissions were successful. But it also illustrates, that a car emitting little or no pollutants in exhaust gases is not purged completely from being environmentally burdening.

From this point of view, measures to reduce other burdens such as CO_2 emissions, road noise, accident casualties and fuel manufacture promise to be more effective to diminish the *overall* burden from modern cars in the future. Also land use aspects (road infrastructure, landscape fragmentation) and material consumption aspects (car manufacture, servicing and disposal) will become increasingly significant, and, for low burdening cars can become more important than fuel-related issues.

It is significant to note that roughly 50% of the total environmental burdens are indirect burdens. Indirect or 'grey' burdens do not occur directly at the place or time the car is used, but are caused indirectly during the whole car life cycle due to eg. fuel manufacture (precombustion) or grey burdens in material consumption.

2.2.3 The results in detail

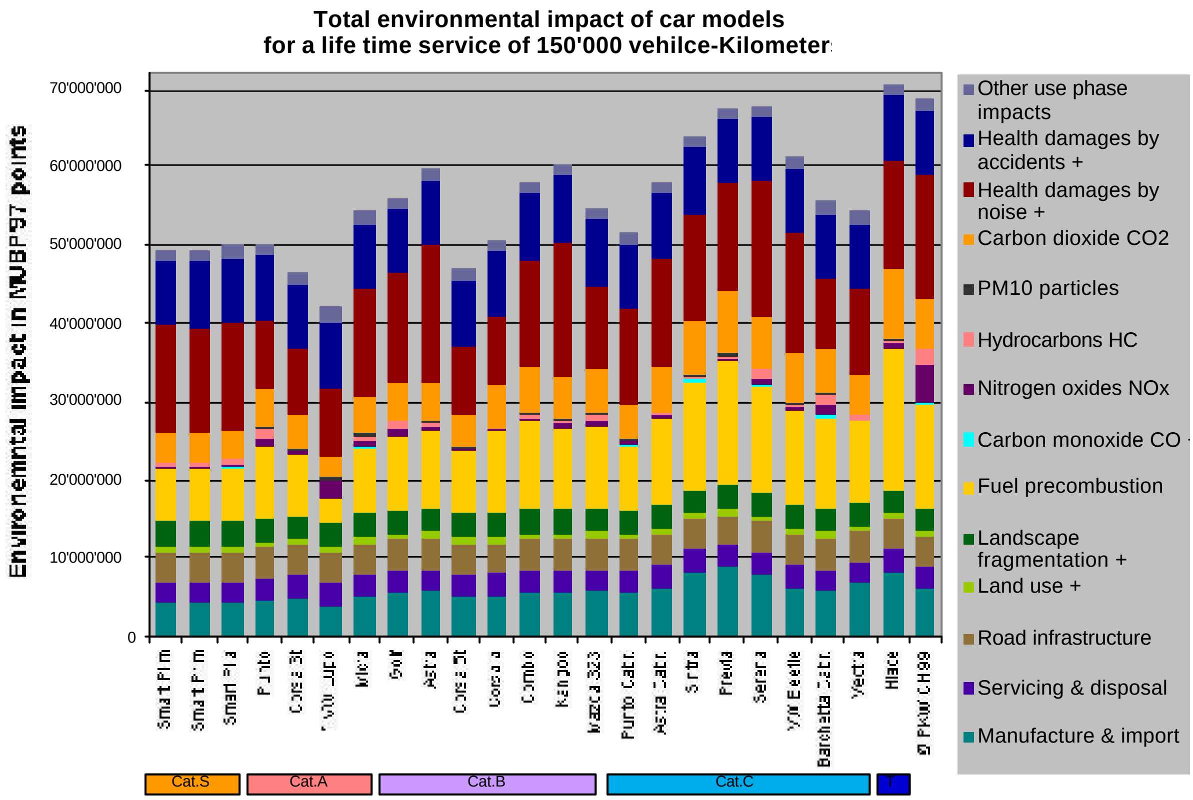
Table 3 lists the car models and numbers of the current Mobility fleet. Figure 3 shows the complete environemntal impact of these cars expressed in MUBP'97-points for a complete life time service of 150'000 vehicle-kilometers.

The least burdening car models are small limousines like VW Lupo TDI 3l, Smart and Opel Corsa. Compared to the average Swiss passenger car the environmentally best car model in the mobility fleet is 39% less burdening (Lupo). However, a minority of the car models have roughly equal than average impacts. These car models are transporters (Hiace) and large passenger vehicles for up to 8 passengers (Previa, Sintra).

Table 3 Car models assessed in this study: 23 car models in 5 categories of the current Mobility fleet. An average Swiss car 1999 is assessed as comparison. The short name for the VW Lupo has a prefix '*' to remind it is a diesel car.

Category	Vehicle Model	Short name	Items in Mobility fleet
Cat. S	Smart & Pulse man.	Smart Pl m	17
Cat. S	Smart & Pure man.	Smart Pr m	17
Cat. S	Smart & Pulse autom.	Smart Pl a	17
Cat. A	Fiat Punto 1.1 S50	Punto	51
Cat. A	Opel Corsa 3 doors	Corsa 3t	129
Cat. A	VW Lupo 3l 1.2 TDI	* VW Lupo	75
Cat. A	Nissan Micra K11	Micra	0
Cat. B	VW Golf 1.4	Golf	28
Cat. B	Opel Astra 1.4	Astra	668
Cat. B	Opel Corsa 5 doors	Corsa 5t	129
Cat. B	Opel Corsa autom.	Corsa a	129
Cat. B	Opel Combo Kasten.	Combo	0
Cat. B	Renault Kangoo 1.4	Kangoo	0
Cat. B	Mazda 323 1.6	Mazda 323	0
Cat. C	Fiat Punto Convertible	Punto Cabr.	10
Cat. C	Opel Astra Convertible	Astra Cabr.	10
Cat. C	Opel Sintra 2.2	Sintra	7
Cat. C	Toyota Previa 2.4	Previa	10
Cat. C	Nissan Serena 1.6	Serena	0
Cat. C	VW Beetle 2.0	VW Beetle	16
Cat. C	Fiat Barchetta 1.7	Barchetta Cabr.	7
Cat. C	Opel Vectra 1.8	Vectra	6
Cat. T	Toyota Hiace 2.7	Hiace	27
	Average car Switzerland	Ø CH 99	

Figure 3 Environmental impact – expressed in MUBP'97-points – for 23 different car models in the 5 categories of the current Mobility fleet. The VW Lupo has a prefix '*' to remind it is a diesel car. A current average Swiss passenger car is shown for comparison.



Generally, diesel cars are often thought to be environmenally worse than petrol cars, due to higher emissions of NO_x and PM10 particles. Also, diesel fuel emits more CO_2 per liter than petrol. On the other hand, diesel motor concepts often show reduced fuel consumption. In the case of the VW Lupo TDI 3l the elevated emissions of NO_x and particles are more than compensated by the high reduction in fuel consumption. This result was confirmed using the valuation method Eco-indicator'95+ (Jungbluth 2000) and is therefore not an artefact of the MUBP'97 valuation method. However, the finding cannot stand for all diesel cars, as the Lupo is remarkably clean and fuel efficient compared to other available diesel car models. The Lupo is the only diesel car in the current Mobility fleet.

LCA results have usually a range of uncertainty of at least 20%. Therefore, it is advisable not to draw conclusions from small differences in the results. Hence the results should be classified into rough categories of comparable environmental load, as is done in Table 4.

Table 4 Rough classification of environmental performance of the car models as compared to the average Mobility car. The models are listed in order of increasing environmental burden.

Rating	Total environmental burden as compared to average Mobility car is	Car models
👍👍	Distinctly smaller	* VW Lupo
👍	Slightly smaller	Corsa 3t, Corsa 5t, Smart Pr m, Smart Pl m, Smart Pl a, Punto, Corsa a, Punto Cabr., Micra, Vectra, Mazda 323
		Average mobility car
👎	Slightly bigger	Barchetta Cabr., Golf, Combo, Astra Cabr., Astra, Kangoo, VW Beetle, Sintra
👎👎	Distinctly bigger	Previa, Serena, Ø PKW CH'99 🇨🇭, Hiace

2.2.4 Contributions to the total impact result

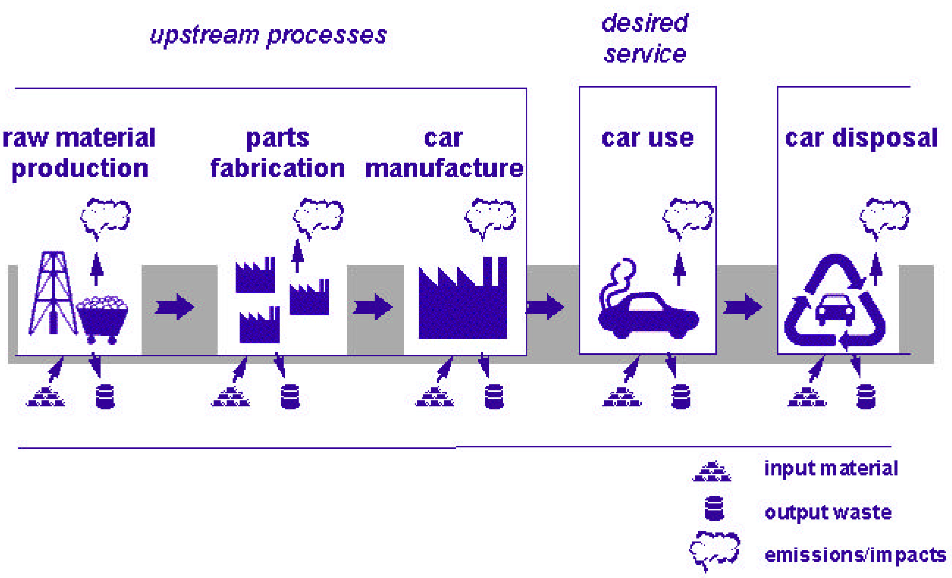
The total impact is composed of various contributions. Below we give a description of these contributions and major influences on their magnitude. Impact contribution entries marked with a suffix '+' could not be covered with the existing BUWAL/UBP'97 method (Brand et al. 1998) and were assessed according to the new valuation procedures developed for the MUBP'97 methodology (Doka 2000) used in this study.

Manufacture & import. In this part all expenditures for the car manufacture (materials and energy) are heeded. Assessed individually to the car models weight. This part basically depends on the manufacturing process and location of the car manufacturer. The consumer has but a very indirect choice of influencing this by either buying or not buying this car. Car manufacturers of course are able to make design choices here, as well as in engine performance issues below (fuel consumption, exhaust gases).

Servicing. In this part all expenditures for the car maintenance (materials and energy) are heeded. Assessed with average data for passenger cars. Energy consumption of servicing stations make up for a good part of this contribution. This is dependent on the station management. Tyre replacement is another bigger influence. Servicing frequency might be partially dependent on driving style but also on the car model.

Disposal. Disposal of the materials used for manufacture and maintenance is heeded here. A total life time of 10 years and 150'000km is assumed. After that the car will be dismantled in Switzerland. Most metal parts are assumed to be recycled. Plastics are incinerated. Assessed individually to the car model. Disposal is first of all a function of the input materials used for the car. Disposal options depend on hand on the existing disposal channels in a region (recycling, incineration), and on the management of dismantling used cars.

Figure 4 Simplified life cycle of a car.
On every stage direct emissions and environmental burdens or impacts are generated. All input materials and output wastes lead to additional indirect or 'grey' burdens accountable to the car.



Road infrastructure. The proportional amount of materials and energy for the national road infrastructure per car are assessed here. Separate effects which are also attributable to the road infrastructure as well are expressed below (land use, landscape fragmentation). Assessed with average data for passenger cars. Road infrastructure is determined by the technical engineering processes of roads on one hand. On the other hand roads are commissioned by political institutions. These in turn react to current situations and extrapolated prognoses on traffic development and propose various solutions to the perceived traffic problems. The vicious circle of "bottleneck traffic situation - new roads as a solution - increased attractivity - new bottleneck on a higher traffic level" is often ignored in this process. It is fair to say that roads generate new roads. It is obvious that this will be unsustainable in the long run and technical solutions of "environmentally friendly road building" are not sufficient to attain sustainability.

Land use +. This is the consumption of land resources from land use due to road infrastructure. Assessed with average data for passenger cars. Land use from road infrastructure is in most cases irreversible, i.e. the roads are only very rarely eliminated once they are built, so there is little possibility to reduce these burdens.

Landscape fragmentation +. Fragmentation of wildlife migrating routes due to highways and busy main roads. Assessed with average data for passenger cars. Currently 73% of the major wildlife migrating routes are not intact. The effects of fragmentation can be alleviated for some animal species by special passages over or under the roads.

Fuel precombustion. Burdens form the manufacture and distribution of fuel (before combustion). Assessed individually to the car models fuel consumption. This part is dependent on fuel consumption which is dependent on the car model, but also driving style, possible extras like air conditioners. Since a cold motor uses more fuel than a warm motor the fuel consumption depends also on the average distance travelled per start (i.e. average trip length). Other influences are type of trip (inner city, highway etc.), driving style, travelling speed. The precombustion is also dependent on the way fuel is produced, which can be influenced by fuel manufacturers, but only slowly since technology changes are merely gradual. The precombustion of diesel fuel has a 20% lower impact per liter than one liter of petrol.

Carbon monoxide CO + , Nitrogen oxides NO_x , Hydrocarbons HC, PM10 particles. These are all direct exhaust emissions. They have various deteriorating effects on human health and on the natural environment. Assessed individually to the car model. Exhaust emissions are dependent on the car model (engine and catalyst type), but also type of trip (inner city, highway etc.), driving style, travelling speed and fraction of cold starts per distance travelled (i.e. average trip length).

Carbon dioxide CO_2. Exhaust emissions of Carbon dioxide. Assessed individually to the car model. Carbon dioxide emissions are dependent on the fuel consumption of the car (see conditions for consumption in the part 'fuel precombustion'). Diesel fuel has a 13% higher carbon content per liter than petrol.

Health damages by noise +. Damages to human health from road noise in residential areas. Assessed individually to the car model. The noise impacts are dependent on the noise level of the car (motor noise and tyre noise), but also driving style and road surface. Since the health damages during the night are much more severe than during the day the impact heavily depends on the distance travelled during the night. For the study an average share of 7% nightdrives (22.00h to 6.00h) was assumed. The impact contribution from noise will be reduced by 23% of the devised figure for car trips only taking place during the day, or will be higher by 427% – or a factor of 5 – for car trips only taking place during the night(!).

Health damages by accidents +. Damages to human health from traffic accidents. Included were casualties and injuries. Assessed with average data for passenger cars. Accident damages are dependent on the driving style, safety belt discipline, speed, alcohol consumption, type of road and weather, and the safety measures in the car design.

Other use phase impacts. Includes other exhaust emissions like sulphur dioxide (SO_2), nitrous oxide (Lachgas, N_2O), lead traces (Blei, Pb). Assessed individually to the fuel type (petrol, diesel) of the car model. Also included here are zinc and cadmium emissions from tyre wear (Assessed with average data for passenger cars). Lead trace emissions are only present in petrol cars (not diesel cars). This applies also to unleaded fuel (as used in Mobility cars) but of course on a lower level than in leaded petrol. Sulphur content of fuels was lowered by manufacturers in the past and is now on a very low level. Zinc and Cadmium emissions from tyre wear are dependent on rubber quality, air pressure, road surface and partially dependent on driving style.

2.2.5 Results per CarSharing category

The cars in the assessment are not comparable in every respect, because they serve different uses. Most of the cars are passenger vehicles. The passenger cars have varying seat capacity from 2 seats (Smart) up to 8 seats (Previa). The Toyota Hiace however is decidedly a pure transport vehicle. Other cars like eg. the convertibles or the Volkswagen Beetle are denoted as 'fun cars' with neither a strict passenger not freight transport utility, and rather serve as a 'transportainment' utility. So strictly the cars are not comparable or exchangeable regarding the delivered service.

Mobility CarSharing rents their vehicles in differently priced categories. These categories (Cat. S, A, B,C, and T) are indicated in the result chart in figure 3. The category prices increase in that same order (Table 5). Since the customers are ready to pay the same amount of money for vehicles within one category, it is fair to say that the cars of this category perform comparable services (based on 'willingness-to-pay'). Therefore, cars within the same category can be considered comparable in terms of the delivered or perceived service.

Table 5 Tariffs for Mobility car use in 5 categories. The tariffs for non-members has a similar structure, but on a higher price level. † the assumed speed over the whole trip is assumed to be 10km/h (= total travelled distance : travel time & stopover time).

Vehicle category	Tariff per hour rent 7.00–23.00h	Tariff per kilometer travelled	Average tariff per km †
S	2.55	0.35	0.605
A	2.55	0.40	0.655
B	2.55	0.50	0.755
C	2.55	0.70	0.955
T	4.20	0.70	1.120

Increasing price of the category generally signifies also an increase of environmental burden (Figure 5). This is not a surprising result, as environmental burden is partially correlated with fuel consumption which in turn will influence prices. An exception is category S, which is cheaper than category A, but produces more burden. Category S obtains a higher environmental burden than category A mainly due to a higher noise level of the models in this category.

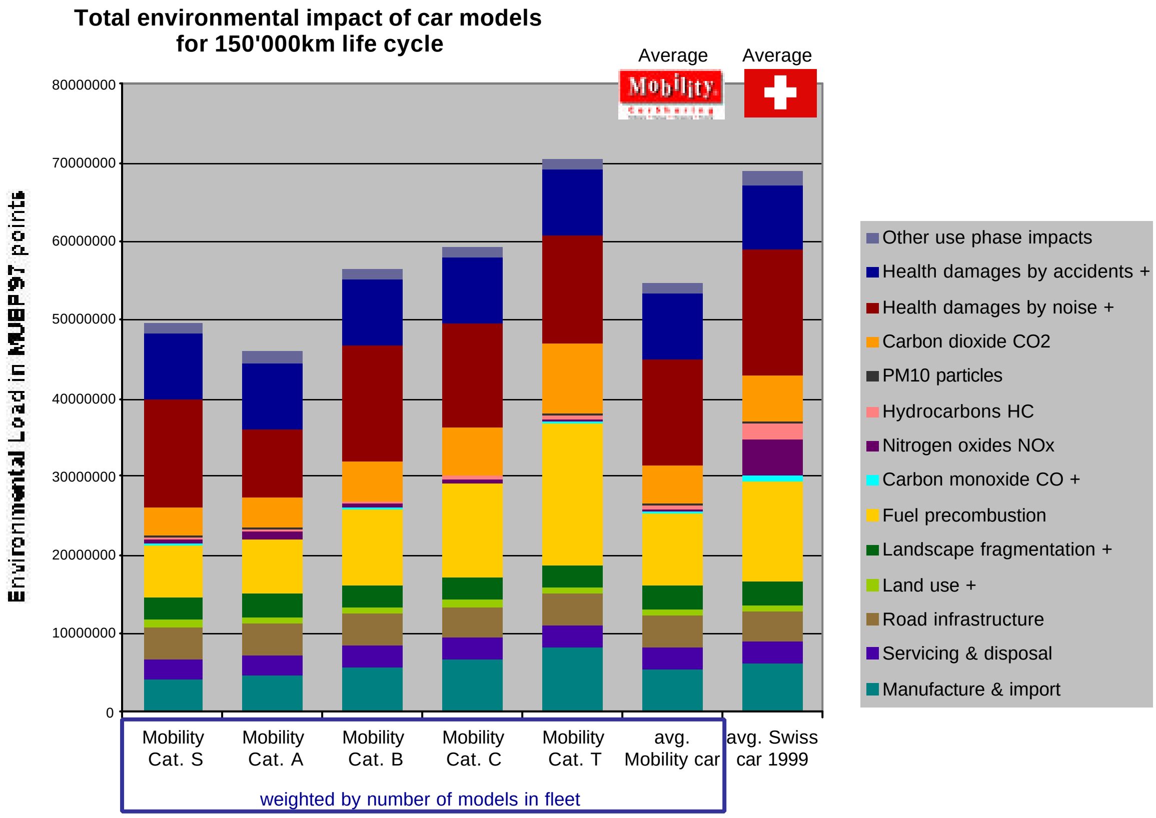
The average Mobility car is 20% less burdening than the average Swiss passenger car.

2.3 Light-weight material and the effects on the environment

Separate analysis for the VW Lupo showed that the increased use of light-weight materials like aluminium and magnesium in modern car concepts is environmentally favourable: The additional environmental burdens caused by the use of these energy intensive materials are compensated through the reduced fuel consumption in the weight-reduced cars. It is advisable to check the environmental trade-off of light-weight materials for each car design individually.

However, average car weight has increased during the last decades, due to increased luxury in cars. The first VW Golf was 100 kilograms lighter than the current VW Lupo TDI 3l. Also changes in engine management promise to have a bigger influence on fuel reduction with a better ecological trade-off than use of light-weight materials.

Figure 5 Environmental burden – expressed in MUBP'97-points – for 5 categories of car models and the average of the current Mobility fleet. A current average Swiss passenger car is shown for comparison.



2.4 Conclusion and outlook

The current study addressed different petrol and diesel car models only. However, an important advantage of the MUBP'97 methodology, compared to the VCS list (Egli et al. 2000), is it's full compatibility with other fuel technologies, like natural gas, methanol, hydrogen or electricity as well as with other modes of passenger transport. In the future, it is easy for Mobility CarSharing Switzerland to assess new car technologies without the need to change the methodology. Additionally, this analysis can be applied to scenarios developed in the yearly planning.

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