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Contents

Zusammenfassung

Die als Folge der wirtschaftlichen Entwicklung gestiegene Nachfrage nach Transportleistungen hat weltweit zu einem Anwachsen der Flotte von Schwerverkehrsfahrzeugen geführt. Die damit einhergehende Verkehrszunahme erhöht die Stauzeiten und trägt wesentlich zu mehr Lärm, einem erhöhten Energieverbrauch, einer Vergrösserung der Schadstoffbelastung sowie zu einer stärkeren Beanspruchung der Infrastruktur bei. Eine langfristig nachhaltige Transportinfrastruktur erfordert daher Instrumente und Steuerungsmöglichkeiten zur Förderung von Fahrzeugen und Technologien mit einem geringen Umwelt-Fussabdruck.

Zur Internalisierung der externen, durch den schweren Güterverkehr verursachten Kosten wurde in der Schweiz die *Leistungsabhängige Schwerverkehrsabgabe*, LSVA, eingeführt. Zur Förderung moderner Motor- bzw. Abgasbehandlungstechnologien berücksichtigt diese Abgabe nebst der Fahrleistung (Distanz und Gewicht) auch die EURO Kategorie. Dieses Anreizsystem verliert allerdings mehr und mehr an Bedeutung, da die neu in Verkehr gesetzten Fahrzeuge sowieso der höchsten EURO Kategorie angehören. Mit der modernen Abgasnachbehandlung von EURO 6 Systemen wird der Schadstoffausstoss sehr stark reduziert, sodass hinsichtlich der Umweltbelastung und der damit verbundenen externen Kosten eine Verschiebung zu anderen Effekten wie Lärm und Infrastrukturschäden auftritt. Wie jüngere Untersuchungen des Autorenteams gezeigt haben garantieren neue Fahrzeuge nicht in jedem Fall günstigere Verhältnisse bei den Lärmemissionen. Es bietet sich daher an, durch eine Neuausgestaltung der Abgabe leisere Fahrzeuge zu fördern. Ziel dieses Projekts ist die Bereitstellung der diesbezüglich relevanten Grundlagen und Relationen zu den externen Kosten.

Die Basis dazu bildete die im ARE Bericht entwickelte Aufstellung der durch Lärm, Schadstoffausstoss und dynamische Belastungen verursachten externen Kosten. Diese Angaben wurden mit Messdaten von Einzelereignissen an der Monitoringstation Oberbuchsiten kombiniert, sodass statistische Aussagen zu den von Güterfahrzeugen verursachten Kosten in den entsprechenden SWISS10 Kategorien abgeleitet werden konnten. Die Analyse zeigt in allen Kategorien grössere Streuungen, die ihrerseits ein bedeutendes Verbesserungspotenzial dokumentieren. In Ergänzung zum reinen Kostenmodell wurde zusätzlich der Eco-Punkte Ansatz (UBP) untersucht.

Basierend auf den Messdaten von Oberbuchsiten wurde ein empirisches Modell zur Schätzung der akustischen Emission von Güterfahrzeugen bei Autobahngeschwindigkeiten entwickelt. Das Modell berücksichtigt die Fahrzeugklasse, die Anzahl Achsen sowie das maximal zulässige Gewicht. Mit a priori Wissen zur relativen Bedeutung von Antriebs- und Rollgeräusch kann das Modell den Effekt leiser Reifen prognostizieren. Bei höheren Fahrgeschwindigkeiten, d.h. auf Überlandstrassen und Autobahnen, stellt das Reifengeräusch einen bedeutenden Anteil am Gesamtgeräusch dar. Zur Abschätzung des in leisen Reifen liegenden Lärmreduktionspotenzials wurde eine Marktanalyse der aktuell verfügbaren Reifen durchgeführt. Die hierbei gefundene Streuung der Reifenlabelwerte von mehr als 3 dB zeigt auf, dass eine Förderung der Verwendung von leisen Reifen zu einer relevanten Lärmminderung führen kann. Gleichzeitig deuten jüngere Untersuchungen darauf hin, dass weitere Anstrengungen zur Konsolidierung der Reifenlabelwerte nötig sind. Zur Illustration der Zusammenhänge wurden fünf verschiedene Lärm-Bonus-Szenarien entwickelt. Hierbei wird gezeigt, dass bezogen auf den Status quo (01.01.2017) ein Lärmbonus von 30 oder 50 % angewendet auf 10 % der Fahrleistung (Tonnen-Kilometer) zu einer Veränderung der Einnahmen von maximal 5 % führt.

In mehreren Workshops mit unterschiedlichen Akteuren aus Entwicklung, Planung und Vollzug wurden folgende Umwelteinwirkungen identifiziert und ausgeleuchtet:

- Treibstoffverbrauch
- CO2 Emissionen
- Schadensentwicklung an Belägen bzw. Geleisen
- Lärm

Im übergeordneten Eurekaprojekt wurden Vorschläge für ein EU Label entwickelt, das die wichtigsten Umweltaspekte zusammenfassen soll. Damit sollen kompetentere Kaufentscheide ermöglicht werden. Darüber hinaus könnte dies als Basis für die Ausgestaltung von umweltorientierten Zugangsgebühren für das Strassen- und Schienennetz dienen und so zur weiteren Internalisierung von externen Kosten, die bisher von der Gesellschaft getragen werden, beitragen.

Résumé

L'accroissement de la demande de prestations de transport due au développement économique a conduit dans le monde entier à une augmentation du nombre des véhicules utilitaires lourds. Cette augmentation s'accompagne d'une augmentation des bouchons, des émissions sonores, de la consommation d'énergie, des émissions de polluants ainsi que d'une usure accrue de l'infrastructure. Pour assurer à long terme une infrastructure de transport durable il est nécessaire de disposer d'instruments de pilotage pour encourager l'utilisation de véhicules et de technologies présentant une faible empreinte environnementale.

Afin d'internaliser les coûts externes provoqués par le trafic des marchandises, la Suisse a introduit la «Redevance sur le trafic des poids lourds liée aux prestations» (RPLP). Pour promouvoir les technologies modernes en matière de motorisation et de traitement des gaz d'échappement, cette redevance tient compte, en plus des prestations de transport (distance et poids) aussi de la catégorie EURO. Ce système d'incitation perd toutefois de plus en plus son sens car les nouveaux véhicules mis en circulation appartiennent de toute façon à la catégorie EURO la plus élevée. Les systèmes d'épuration de gaz d'échappement modernes qu'implique la norme EURO 6, diminuent très fortement les émissions de polluants de sorte qu'il se produit pour la charge exercée sur l'environnement et ainsi aussi pour les coûts externes, un déplacement vers d'autres effets tels que le bruit et les dommages causés à l'infrastructure. Comme l'ont montré des études récentes menées par les auteurs, les nouveaux véhicules ne sont pas toujours la garantie d'émissions de bruit plus faibles. Il serait donc indiqué de réaménager cette redevance afin de promouvoir les véhicules moins bruyants. Le but de ce projet et de fournir les bases nécessaires à ce réaménagement et d'établir leurs relations avec les coûts externes.

Pour cela, on a utilisé les données du rapport de l'ARE sur les coûts externes provoqués par le bruit, les émissions de polluants et les charges dynamiques. Ces données ont été combinées avec les données de mesure de véhicules individuels récoltées sur le site de monitorage de Oberbuchsiten pour obtenir ainsi des informations statistiques sur les coûts externes des véhicules pour chacune des catégories de véhicules SWISS 10. L'analyse de ces résultats révèle une dispersion importante des valeurs dans toute les catégories, dispersion qui témoigne d'un potentiel d'amélioration important dans chacune d'elles. En complément du modèle des coûts seuls, on a encore déterminé les écopoints (UBP) de chacune des catégories de véhicules.

A partir des données de mesure de Oberbuchsiten on a développé un modèle empirique pour l'estimation des émissions acoustiques des véhicules utilitaires aux vitesses de circulation sur autoroute. Ce modèle tient compte de la classe de véhicule, du nombre d'essieux ainsi que de la charge maximale admissible. A partir de la relation connue entre le bruit du moteur et le bruit de roulement, ce modèle permet de pronostiquer l'effet de pneumatiques plus silencieux. Aux vitesses élevées, soit sur les routes principales et les autoroutes, le bruit des pneumatiques représente une part importante du bruit total. Pour estimer le potentiel de réduction du bruit que recèlent les pneumatiques plus silencieux on a procédé à une étude des pneumatiques actuellement disponibles sur le marché. La dispersion des valeurs du label de pneumatique européen de plus de 3 dB qui ressort de cette étude montre que la promotion de l'utilisation de pneumatique plus silencieux peut conduire à une réduction importante des émissions de bruit. Simultanément, des études récentes montrent qu'il est nécessaire de poursuivre les efforts pour l'amélioration des valeurs des labels des pneumatiques. Pour illustrer ces relations, cinq scénarios de bonus-bruit ont été établis. Ces scénarios montrent que, par rapport au statu quo (01.01.2017), un bonus-bruit de 30 ou 50 % appliqué sur 10 % des prestations (tonnes-kilomètres) conduit à une modification des recettes d'au maximum 5 %

Lors de plusieurs ateliers de travail avec différents acteurs du développement, de la planification et de l'exécution, les facteurs suivants qui exercent un impact important sur l'environnement ont été identifiés et examinés:

- Consommation de carburant

- Emissions de CO2
- Endommagement des revêtements ou des voies
- Bruit

Dans le projet Eureka supra-ordonné, des propositions ont été développées pour un label UE qui tienne compte de ces aspects environnementaux importants. Ceci afin de permettre aux acheteurs de véhicules de prendre leur décision d'achat avec plus de compétence. Par ailleurs ces propositions pourraient aussi servir de base pour l'établissement de taxes d'accès au réseau routier ou ferroviaire reposant sur l'empreinte environnementale et contribuer ainsi à l'internalisation de coûts externes jusqu'ici supportés par la société.

Summary

Greater demands on the road transport infrastructure as a result of economic growth have manifested themselves in an increase in the number of Heavy Duty Vehicles (HDV) worldwide. This increase is inherently accompanied by increase in congestion, noise, energy use and pollutant emissions as well as an increase in the infrastructure overuse. For a sustainable transport infrastructure, comprehensive instruments are needed in order to encourage vehicles with a low environmental footprint. The Swiss heavy vehicle charge (HVC) (Leistungsabhängige Schwerverkehrsabgabe or LSVA) has been introduced in order to internalize the external costs of HDVs by introducing a variable charge based on the engine polluting potential or EURO categories and transport performance. However, as the trend shows, vehicles belonging to polluting EURO categories are rapidly replaced by clean vehicles, the differential charging currently implemented by the LSVA does not fulfill the intended goals of recovery of the external costs of road transport in the longer term. Especially since the current differential charging categories are purely based on pollutant emissions but external costs are also produced by other effects such as noise and damage to infrastructure. Previous research by the authors has shown that the newer vehicles are not necessarily less noisy. Therefore the current instruments do not encourage low noise vehicles and new instruments need to be developed to encourage these.

This project aimed to relate the environmental footprint of heavy duty vehicles to external costs incurred by such vehicles. To this end, the external costs of transport reported by the report from ARE from noise, gaseous emissions and dynamic load was used. This data was related to the individual impact of each vehicle using data collected from a Swiss monitoring site in Oberbuchsiten between Zurich and Bern to estimate the external costs of individual vehicles. To this end, using a data set the cost of noise, emissions and damage to infrastructure was calculated for Swiss heavy vehicle categories. The data shows that in each category there are vehicles with high impacts and therefore costs and those with low impacts demonstrating the potential for improvement in each vehicle category. Noise and emissions impacts were added using Eco-points (UBPs) to demonstrate the environmental effects of heavy vehicle categories.

Three noise emission models for highway speed regimes were developed and expanded to demonstrate the effect of using low noise tyres using the noise data obtained at the Oberbuchsiten site in 2011 using the following parameters: vehicle classification, number of axles and maximum allowable weight. Furthermore, the noise model was expanded for an urban speed regime (<50km/h).

One of the instruments in reducing traffic noise is the tyre and therefore the low noise tyres currently available are of particular interest for this project. The variance in noise emissions of the available tyres currently on the market (>3 dBA) shows that there is a great potential to lower traffic noise by using low noise tyres. Five scenarios were developed in order to introduce a noise bonus of 30% or 50% of the LSVA for 10 % of the tonne-kilometers transported demonstrating the hypothetical gain or loss of revenue of maximum 5% in comparison to the status quo (01.01.2017). The current limited in situ data indicates that more research needs to be carried out verifying the in-situ noise emissions of low noise tyres.

In a series of workshops with stakeholders, the major environmental impacts have been identified and reviewed. These are –

- fuel consumption
- carbon dioxide emissions
- damage to the pavement or track
- audible noise

and it is proposed to capture this vehicle information in an EU-type label. By bringing these impacts together it will enable the buyers to purchase a vehicle which meets their needs and is also environmentally friendly. It could also provide a basis for applying road

usage or track access charges and for internalising some of the external costs currently carried by society.

1 Background

Greater demands on the road transport infrastructure as a result of economic growth have manifested themselves in an increase in the number of Heavy Duty Vehicles (HDV) worldwide. This increase is inherently accompanied by increase in congestion, noise, energy use and pollutant emissions as well as an increase in the infrastructure overuse. Although noise and infrastructure costs are primarily local effects, the increase in transport induced greenhouse gases (GHG) is a global problem contributing significantly to climate change and must be dealt with globally. To this end, comprehensive instruments are needed in order to encourage vehicles with a low environmental footprint.

The impact of internal combustion engines on **polluting** the environment is undisputable. The primary greenhouse gases produced by the transportation sector are mainly carbon dioxide (CO_2), methane (CH_4) and nitrogen oxides (NO_x). Nitrogen oxides are one of the important precursors for the formation of secondary particles and ozone in the atmosphere, causing regional haze. Diesel particulate matter is a major toxic air pollutant with adverse effects on human health, and in particular, the ultrafine particles in 30-100 nm size range. A critical review of the impact of diesel engines on the environment is presented in the example from California USA that shows how such an impact needs to be controlled [10]. Consequently, in the United States and Europe very stringent pollutant emission limits have been introduced (U.S. 2010 and Euro-VI).

In Switzerland protection of the alpine region has high priority. As of January 1st 2001 a new heavy vehicle charge (HVC) (Leistungsabhängige Schwerverkehrsabgabe or LSVA) has been introduced in order to internalize the external costs of HDVs by introducing a variable HVC [3][12]. It replaced the previous HVC that was a flat fee. The revenues are used as follows: one third of the funds raised through the LSVA go to the Cantons to cover uncovered costs of heavy transport and two thirds go to the federal government for financing of large public transport projects. The fee is calculated using the allowable gross vehicle weight, distance travelled and engine type approval category (EURO category). The goal of the LSVA that is based on the “user/polluter pays principle” was threefold. First, to limit the growth of road heavy goods vehicle traffic, second, to transfer freight from road to rail and third to protect the environment. One of the positive effects of the LSVA has been the reduction in air polluting emissions from HDVs. This is mainly due to more efficient transportation of goods through the use of full vehicles, reduction in mileage and use of newer engine technologies with low pollutant emissions. Fleets have been upgraded; as reported by the federal office for spatial development (ARE), the percent of kilometers travelled with EURO V which up to 2012 was the most environmentally friendly has considerably increased [4][5][6][7].

Starting with EURO VI, heavy duty vehicles have to fulfil tight emission limits not only during certification but also during real operation. This so-called Real Driving Emissions (RDE) are monitored for 7 years or 700’000 km using portable emission measurement equipment. In contrast to this very strict heavy duty vehicle emission regulation, passenger cars do not have such RDE legislation yet. This leads to the fact that many Diesel passenger cars emit much more NOx in real world driving compared to the emissions in the test cycle which is not the case for HDVs.

However, as the trend shows, vehicles belonging to polluting EURO Categories are rapidly replaced by clean vehicles belonging to categories of EURO V [14] and EURO VI, the differential charging currently implemented by the LSVA does not fulfill the intended goals in the longer term any more. Especially since these categories are purely based on pollutant emissions but external costs are also produced by other effects such as noise and damage to infrastructure.

A recent report by the World Health Organization (WHO) indicates that in the EU and Norway, traffic **noise** is the second biggest environmental problem affecting health after air pollution [13]. This new health evidence highlights the urgency of adopting more stringent vehicle noise standards. The European Commission is expected to release a proposal to update the Vehicle Noise Directive issued in 2012 [Directive 70/157/EEC]. Further evidence by WHO indicates that noise can disturb sleep, cause cardiovascular and psychophysiological effects, reduce performance and provoke annoyance responses and changes in social behavior. Traffic noise alone is harming the health of almost every third person in the WHO European Region. One in five Europeans is regularly exposed to sound levels at night that could significantly damage health [14]

Roads are a substantial asset to the economy of every country. Overloaded vehicles can destroy this asset at an accelerated rate. In many countries there is legislation in place to regulate **overloaded vehicles** for a sustainable road infrastructure. In order to increase sustainability of road traffic and at the same time guarantee economic growth it is imperative to develop systems and policy to recognize environmentally friendly HDVs. Directive 1999/62/EC (amended 2006/38/EC) of the European Commission is in place for harmonization of levy systems and fair mechanisms for charging for infrastructure costs in order to eliminate distortions of competition between transporters in member states. It is explicitly stated in this directive that minimum rates should be set for vehicle taxes and that road-friendly and less polluting vehicles should be encouraged through differentiation of taxes or charges.

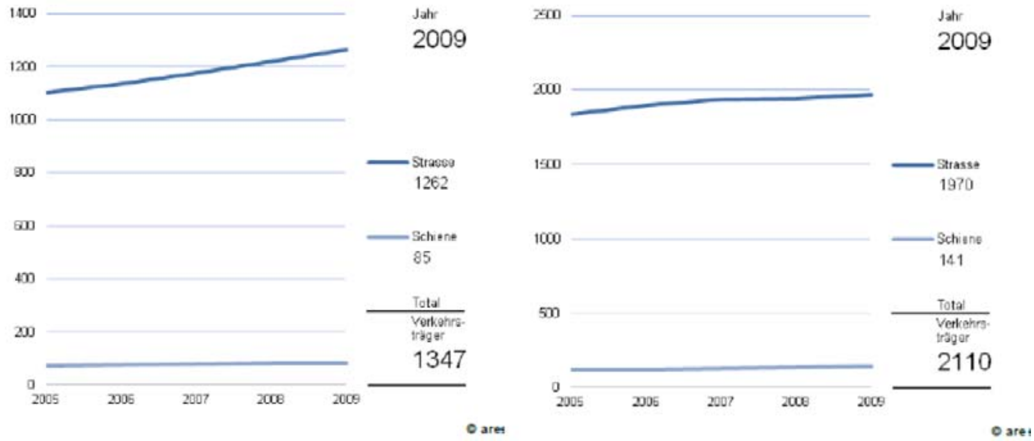


Fig. 1 *cost of noise (left) and pollutants (right) for road and rail transport in Switzerland in mio CHF per year [ARE, 2012]*

The Swiss federal office for spatial development (ARE) publishes a report regularly summarizing the external costs of road and rail transport. As shown in Fig.1 the contribution of road transport to noise and pollutant emissions is considerably higher than rail. The total cost of noise for land transport in 2009 was 1'347 mio. CHF. Similarly in 2009 the external cost of pollutant emissions was 2110 Mio CHF with road transport being the cause of 93% of this [7].

The Swiss heavy vehicle charge (LSVA) is regulated by federal law (Schwerverkehrsabgabegesetz/Federal Heavy Vehicle Charge Act SVAG) [1] and it should cover long-term all infrastructure and external costs of transport that are not covered by the users. Therefore these costs should be quantified regularly so that the LSVA can be adjusted as required by the federal law. A latest report by the federal office for spatial development documents the latest costs as discussed in detail in section 4.

2 Project Overview

This project aims to relate the environmental footprint of heavy duty vehicles to external costs incurred by such vehicles. To this end, the external costs of transport from noise, gaseous emissions and dynamic load were related to the individual impact of each vehicle using data collected in 2011 from a Swiss monitoring site in Oberbuchsiten between Zurich and Bern. The work program was as follows:

1. Measured impacts were related to costs reported in the ARE report [11].
2. Noise emission model for HDV was developed.
3. Previous work by the authors had shown that the EURO V emissions classes that are the most abundant environmentally friendly vehicles regarding their gaseous emissions, are not necessarily less noisy. It was concluded that new instruments have to be developed in order to encourage vehicles with a low noise footprint. Based on the data recommendations were made for the update of the Swiss heavy vehicle charge (LSVA) in order to encourage low noise vehicles.
4. A holistic approach is used taking into account a combination of HDV individual footprints regarding carried load, noise and gaseous emissions, showing the distribution of combined impacts in each vehicle category.
5. In cooperation with European partners eight workshops were organised addressing the environmental footprint of HDV and options to reduce these.

3 Eureka Project Ecovehicle E!7219 and Swiss Contribution

Switzerland has been a member of the European cooperative project Eureka Logchain Footprint since 2004. The project has been successful in developing methods to identify environmentally friendly vehicles for road and rail transport modes [www.eureka.be, [20] [21][22][13][23][24]. The footprint of vehicles was defined within this project as dynamic load, noise, gaseous emissions and vibrations. The contributions of the Swiss partners have been in three phases. In phase I; a footprint monitoring site was installed in order to measure the footprint of passing vehicles using innovative techniques. In phase II it was shown that parameters that are currently controlled and their reduction encouraged such as gaseous emissions, axle loads and gross weight are for the most part below or close to acceptable limits. However other important parameters such as tyre pressure and noise remain to be higher than acceptable limits. In Phase III it was shown that there was no systematic dependence of the noise emissions on the EURO emissions classes for each Swiss 10 category. This shows that the EURO V emissions classes that are the most abundant environmentally friendly vehicles regarding their gaseous emissions, are not necessarily less noisy. It was concluded that new instruments have to be developed in order to encourage vehicles with a low noise footprint. In addition a noise emission model was developed, allowing the individual footprint of a vehicle to be estimated from parameters that are known or observable. Furthermore, 2 Models were proposed for the calculation of the total footprint of heavy vehicles. With the help of the total footprint models developed, heavy duty vehicles could be evaluated using a holistic approach taking into account a combination of all their individual footprints. The results show that in almost every category there are vehicles with a very high combined footprint, showing the potential for reducing this footprint.

The differential charging scheme successfully implemented by the LSVA will not be effective in the longer term in encouraging vehicles with a low total environmental footprint as the updated vehicle fleet is mostly EURO V which was shown is not necessarily less noisy. Noise from road traffic incur significant external costs, these costs are well recovered by the Heavy vehicle charge, but – since noise is not a criteria in the charging scheme - there is no incentive to purchase less noisy vehicles.

The Federal Office for Spatial Development started the initiative to develop the background to revise the LSVA resulting in the three federal departments to support the research project ASTRA 2014/001 starting in 2014.

The European cooperative project Eureka Ecovehicle (E! 7219) had the following global aims:

to develop an environmental label for road and rail vehicles

to relate impacts to costs for individual vehicles

In order to achieve the goals of the project, five tasks were defined as shown below:

Task 1: refining measurement techniques (data quality)
Task 2: methods of informing operators (what/how/ when)
Task 3: developing an environmental label for road and rail vehicles
Task 4: relating impact to costs
Task 5: dissemination (workshops, paper, conferences)

Switzerland has coordinated the project that was managed by Sciotech projects UK. The project received Eureka label E!7219 in 2014 which is necessary to get funding in some member countries. The members of the project were Switzerland (Empa, Quantis, Kistler); Czech Republic (SVUM), United Kingdom (Transport for Scotland, Sciotech Projects, q-free).

Within task 1 the quality of data was analysed and methods developed for checking weigh-in-motion (WIM) data. These results are summarized in the paper in annex II. Task 2 has been inactive as the partners interested in this task (transport for Scotland) have dropped out of the project. Task 3 was the topic of workshop 5 which is summarized in annex II. Furthermore categories for vehicles were identified in Chapter 10. Within task 4 costs were related to impact and this part is summarized in Chapters 5 and 8. Within task 5 a web site was established to allow dissemination of the information within the project. Several conference and journal publications were produced as summarized in chapter 14 and eight workshops were organised at Empa to address various aspects of the project. A summary of these workshops is provided in annex II.

The primary contribution of the Swiss team was to tasks 3, 4 and 5 although data was delivered for task 1 (shown in annex I). As such the data from a Swiss monitoring site was used to produce a total footprint of individual vehicles, and relate these footprints to the external costs and provide based on the data and the future development of vehicles recommendations for the revision to the LSVA.

4 Swiss Heavy Vehicle Charge

As of 1st January 2001 a heavy vehicle charge (HVC) (Leistungsabhaengige Schwerverkehrsabgabe or LSVA) has been introduced in Switzerland by law in order to internalize some of the external costs of road transport [12]. The LSVA is a variable HVC that considers some of the external costs of heavy goods vehicles (HGV). It replaced the previous HVC that was a flat fee. A detailed presentation of the LSVA can be found elsewhere [4][12]. The introduction of the LSVA was in conjunction with the increase in the allowable weight limits for HGV from 28 to 34 t and then to 40 t in 2005 on all Swiss roads [4][5][7][8]. The goal of the LSVA that is based on the ‘‘polluter pays principle’’ was threefold. Firstly, to limit the growth of road heavy goods vehicle traffic, secondly, to transfer freight from road to rail and thirdly to protect the environment. The LSVA applies to HGV over 3.5 t and is calculated based on three criteria:

Number of kilometres travelled in Switzerland

Allowable (declared) gross vehicle weight of the vehicle

The gaseous emissions of the vehicle based on the vehicle engine type approval record (EURO category)

At the introduction of the LSVA the price was calculated based on the above at 1.68 Rappen (Rp or CH cents) pro tonne and kilometres (Rp/t-km) for trucks that meet Euro I requirements. In 2005 this value was increased to 2.44 and as of 1 January 2008 to 2.70 Rp/t-km. Vehicles with Euro 0 would pay more and with Euro II/III would pay less [12]. In order to further encourage vehicles with environmentally friendly engines as of 1 January 2009 the three emission categories were revised (http://www.ezv.admin.ch)

EU emission limits for heavy duty vehicles (HDV) engines were introduced in 1992 (EURO I). These limits were successively tightened in 1995 (Euro II), 2000 (Euro III), 2005 (EURO IV), 2008 (EURO V) and 2013 (EURO VI). For the type approval of HDV engines, their emissions are measured under exactly defined ambient conditions with a reference fuel on engine test benches. EURO VI was the strongest tightening in history of emission regulation since NOx was massively reduced, a particle number limit was introduced enforcing particle filtering technologies; the test cycle was made more stringent by the introduction of an engine cold start. In addition, the engines do not have to fulfil emission limits during certification only but also in use, where emissions can be checked using portable emission measurement systems and the engine manufacturer has to guarantee the fulfilment of emission limits for 700’000 km.

The heavy vehicle charge until 2016 and the bonus malus rate of 15% for domestic vehicles is shown in **Tab. 1** indicating the average charge for EURO III with bonus and malus for other categories.

***Tab. 1** Current heavy vehicle charge and bonus/Malus rate in Switzerland (http://www.ezv.admin.ch/zollinfo_firmen/04020/04204/04208/04744/index.html?lang=de, accessed 8.1.2015), Rp= Swiss cents*

		Rp/t-km	% bonus/ malus	Euro II,III with part filt CH Ct/t-km	% bonus/ malus
Cat 1	Euro 0,I,II	3.1	+15.2	2.8	-3.7
Cat 2	Euro III	2.69		2.4	-10.0
Cat 3	Euro IV+	2.28	-15.2		
	Euro VI	2.05	-23.8		

As of January 1st 2017 the federal office of transport (FOT/BAV) has updated the LSVA as follows [9]:

- Move EUROIII to the expensive category
- EUROIV and EUROV to the middle category
- Removal of the bonus for EUROVI.

This change will result in new tariffs shown in Tab. 2, where the top table indicates the current situation and the bottom as of January 2017. In addition the charge for a 40t vehicle travelling 300 km is shown. According to the bi-lateral agreements between Switzerland and the EU this sum is limited to 325CHF for the weighted average overall provided transport performance and 380CHF for the most polluting category.

***Tab. 2** Current LSVA Tariffs top and the planned ones as of January 2017 bottom [9]*

	Abgabekategorie 1			Kat. 2	Abgabekategorie 3		
Emissionsnorm	EURO 0	EURO I	EURO II	EURO III	EURO IV	EURO V	EURO VI
Tarif pro Tonne und km (tkm)	3,10 Rp	3.10 Rp	3.10 Rp	2.69 Rp	2.28 Rp	2.28 Rp	2.05 RP

Tabelle 26: LSVA-Tarife: heutiges Modell.

Modell ab 1. Januar 2017

	Abgabekategorie 1				Abgabekategorie 2		Kat. 3
Emissionsnorm	EURO 0	EURO I	EURO II	EURO III	EURO IV	EURO V	EURO VI
Tarif pro tkm	3,10 Rp	3.10 Rp	3.10 Rp	**3.10 Rp**	**2.69 Rp**	**2.69 Rp**	**2.28 RP**
Preis für 300 km mit 40 Tonnen	372 CHF	372 CHF	372 CHF	**372 CHF**	**322.80 CHF**	**322.80 CHF**	**273.60 CHF**

Tabelle 27: LSVA-Tarife: Modell ab 01.01.2017.

5 External Cost of Transport in Switzerland

A recent study by the Swiss federal office of spatial development (ARE) has documented the external costs of transport [11]. The study calculates the external and social (national economic) environmental, accident and health-related effects of transport in Switzerland in 2010. In doing so, previous calculations relating to road and rail transport are subject to a methodological review, and recalculated for 2010 using fully updated data. As shown in Fig. 2 the following 12 cost areas were considered: air pollution-related damage to health, damage to buildings, crop shortfalls, forest degradation, loss of biodiversity, noise, climate change, nature and the landscape, soil degradation, upstream and downstream processes, accidents, and additional costs in urban areas. In addition, the external costs of air and waterborne transport in Switzerland are calculated for the first time. Furthermore, the road transport section of the study has been extended to include non-motorised transport such as pedestrian and cycle traffic. The positive effects on health of physical exercise involved in non-motorised transport are also quantified. Aggregated across the four modes of transport, total external costs are CHF 9'400 million for 2010. At CHF 5'500 million, private motorised road transport is the main source of these external costs, followed by road freight transport at CHF 100 million (a share of the HVC has been factored in as an internalisation measure), with public road transport, having a contribution of CHF 190 million. Air transport resulted in external costs of CHF 920 million, while rail transport accounts for CHF 740 million. Waterborne transport generated external costs of CHF 57 million. In addition to external costs of CHF 900 million, non-motorised transport generates external health benefits worth CHF 1'300 million. The significant differences in distances travelled using the individual modes of transport must be considered when comparing these absolute figures. Considerably more person and tonne kilometres are transported by road than by other modes of transport, while figures for waterborne transport are much lower.

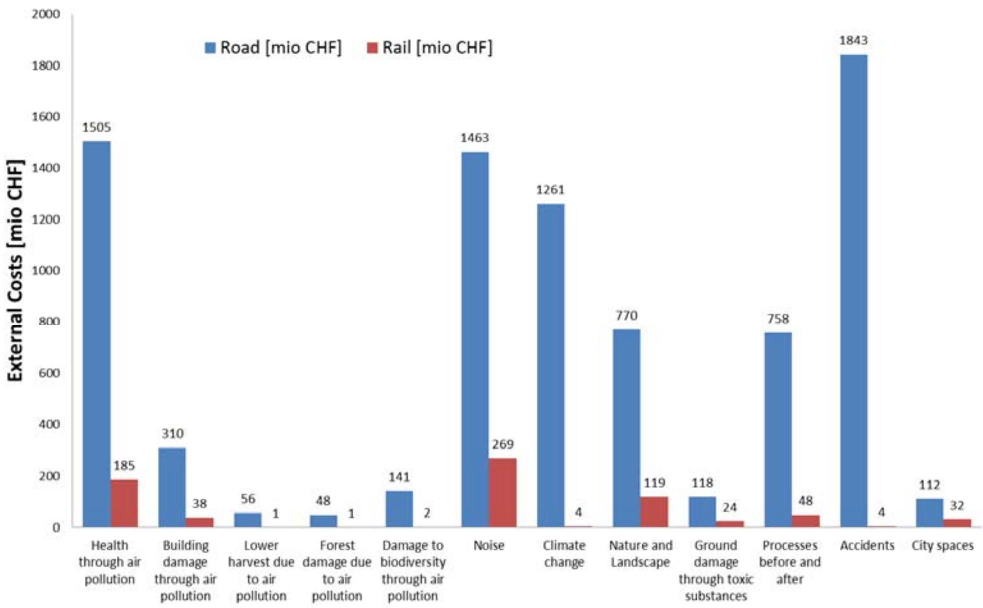


***Fig. 2** External costs of transport for road and rail transport modes [11]*

The report shows that the road freight traffic cost 7.1 Rp/tkm of which 4.4 Rp/tkm was internalised through the heavy vehicle charge (LSVA), implying in turn that 2.7 Rp/tkm was not covered by the charge (Fig. 3). The external cost of rail on the other hand were 2.8 Rp/tkm, air freight 7.6 Rp/tkm whereas ship on the Rhein was 0.5 Rp/tkm

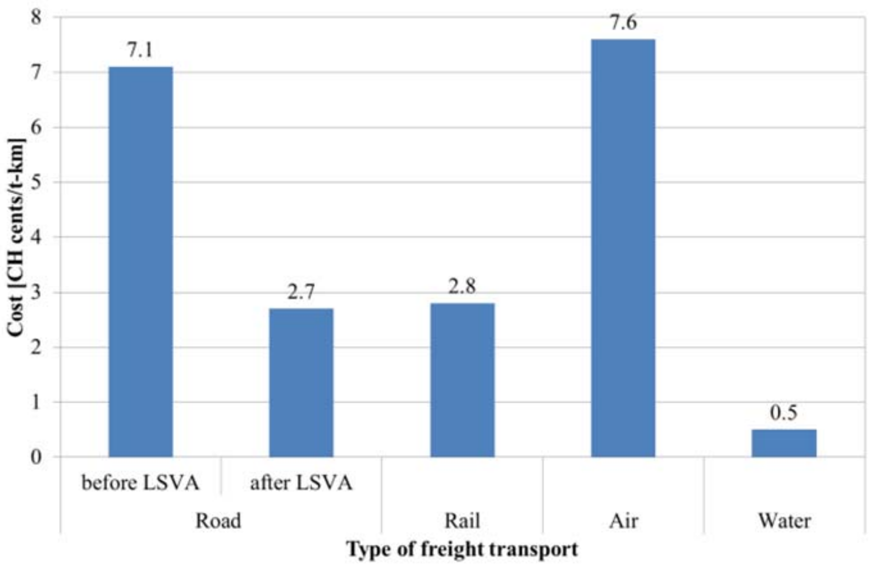


***Fig. 3** Swiss freight traffic: external costs pro tonne kilometre in 2010 [11]*

Furthermore these external costs have been defined for various types of heavy vehicles as follows: The total external costs of heavy vehicles that are paying the charge are 1'293 Mio CHF. These costs are partially covered by the LSVA in the amount of 720 Mio CHF. This means that the remaining 573 Mio CHF are not recovered of which the freight trucks (Lastwagen) bear 65%, articulated and semi-trucks (Sattelschlepper) 24% and buses (Gesellschaftswagen) 11% (Fig. 4).

Externe Kosten Sicht Verkehrsart Strassenverkehr	Gesellschafts-wagen	Lastwagen	Sattelschlepper	**Total**
Gesundheit Luft	22.7	169.4	94.9	287.0
Gebäude Luft	4.7	34.9	19.5	59.0
Ernteausfälle Luft	1.2	10.0	6.9	18.1
Waldschäden Luft	1.0	8.0	5.5	14.5
Biodiversitätsverluste Luft	2.3	18.8	13.0	34.0
Lärm	17.2	233.6	137.8	388.6
Klima	9.5	94.8	68.6	173.0
Natur und Landschaft	4.0	53.5	36.1	93.6
Bodenschäden	2.2	26.2	15.5	43.9
Vor- und nachgelagerte Prozesse	4.8	56.4	46.8	108.0
Unfälle	6.4	33.1	17.0	56.4
Städtische Räume	0.8	8.5	7.0	16.3
Zwischentotal aller Kostenbereiche	**76.5**	**747.3**	**468.7**	**1'292.6**
Abzug LSVA-Anteil	12.5	375.1	332.1	719.7
Total aller Kostenbereiche (mit LSVA Abzug)	**64.0**	**372.2**	**136.7**	**572.9**
in % des Gesamttotals	11%	65%	24%	100%

***Fig. 4** External costs per road vehicle type in Switzerland [11]; for the English translation of the cost areas please refer to Fig. 2*

An important factor to be considered here is the number of vehicles, the driven kilometres and the tonnes transported. Taking into account all these factors allow to consider the social costs and benefits as for example the larger vehicles carry more tonnage (Fig. 5). As seen in the Fig. 5, trucks (LW) and semis (SS) have similar costs regarding noise (Lärm) but not pollution (Gesundheit Luft).

Externe Effekte pro Fzkm Strassenverkehr	Personenverkehr: Motorisierter privater Personenverkehr PW	GW	MR	Mofa	Langsamverkehr Velo	fäG	Fuss	Öffentlicher Personenverkehr Bus	Trolley	Tram	Güterverkehr Li	LW	SS
Mio. Fzkm													
Grundlage Gesundheit / Gebäude Luft	57'418.0	119.0	2'264.5	144.5	2'116.0	113.8	4'894.9	250.0	27.0	28.4	3'607.0	1'449.0	855.0
Grundlage Lärm	53'023.4	123.1	1'790.0	137.7	2'116.0	113.8	4'894.9	253.9	28.1	29.6	3'792.2	1'556.6	918.4
Grundlage Übrige	50'948.6	118.3	1'720.0	132.3	2'116.0	113.8	4'894.9	244.0	27.0	28.4	3'643.8	1'400.6	826.4
Rp. pro Fzkm													
Gesundheit Luft	1.8	19.1	0.4	0.4	-	-	-	24.1	n.a.	n.a.	3.6	11.7	11.1
Gebäude Luft	0.4	3.9	0.1	0.1	-	-	-	4.9	n.a.	n.a.	0.7	2.4	2.3
Ernteausfälle Luft	0.1	1.0	0.0	0.0	-	-	-	1.5	-	-	0.2	0.7	0.8
Waldschäden Luft	0.0	0.8	0.0	0.0	-	-	-	1.2	-	-	0.1	0.6	0.7
Biodiversitätsverluste Luft	0.2	1.9	0.1	0.0	-	-	-	2.8	-	-	0.3	1.3	1.6
Lärm	1.2	13.9	13.9	1.2	-	-	-	13.9	1.2	3.8	3.8	15.0	15.0
Klima	1.9	8.0	1.0	0.6	-	-	-	10.7	-	-	2.4	6.8	8.3
Natur und Landschaft	1.2	3.3	0.5	0.4	0.2	0.1	0.1	3.8	0.4	0.4	1.3	3.8	4.4
Bodenschäden	0.1	1.9	0.1	0.1	-	-	-	1.9	1.9	0.0	0.3	1.9	1.9
Vor- und nachgelagerte Prozesse	1.1	4.0	0.5	0.4	0.6	0.4	0.4	4.7	7.0	21.9	1.4	4.0	5.7
Unfälle	1.2	1.5	15.0	44.6	21.3	40.3	7.4	1.3	9.5	5.1	0.9	1.0	0.8
Städtische Räume	0.2	0.3	0.1	0.1	-	-	-	0.9	1.4	2.2	0.3	0.3	0.4
Gesundheitsnutzen Langsamverkehr	-	-	-	-	-18.4	n.a.	-18.2	-	-	-	-	-	-
Total aller Kostenbereiche	9.2	59.7	31.7	47.9	3.7	40.9	-10.3	71.8	21.3	33.4	15.2	49.5	52.8
Abzug LSVA-Anteil	-	10.6	-	-	-	-	-	-	-	-	-	26.8	40.2
Total mit LSVA Abzug	9.2	49.1	31.7	47.9	3.7	40.9	-10.3	71.8	21.3	33.4	15.2	22.7	12.6
Total Teilbereiche		10.1				-5.3			63.7			29.0	
Gesamttotal Sicht Verkehrsart		53.4										24.4	14.4
Gesamttotal Sicht Verkehrsteilnehmende	10.5	54.9	35.2	52.2	4.7	45.1	-10.0	77.3	59.8	57.4	16.9	24.5	14.4
Gesamttotal soziale Kosten	18.6	83.0	94.2	221.9	-73.6	208.9	-135.5	96.6	225.0	145.7	26.4	57.9	59.5

PW = Personenwagen, GW = Gesellschaftswagen, MR = Motorrad, fäG = fahrzeugähnliches Gerät, Fuss = Fussverkehr, Li = Lieferwagen, LW = Lastwagen, SS = Sattelschlepper, n.a. = not available (nicht verfügbar)

Fig. 5 *External costs per driven km per road vehicle type in Switzerland Rp/vehicle km [11] ; for the English translation of the cost areas please refer to Fig. 2*

Considering the travelled kilometres and transported tonnes as shown in Fig. 6, trucks (LW) cost more per t-km as semi's (SS) with 9.5 vs. 5.0, where noise (Lärm) and pollution (Gesundheit Luft) have a significant contribution.

Externe Effekte pro pkm / tkm Strassenverkehr	Personenverkehr in Rp / pkm: Motorisierter privater Personenverkehr PW	GW	MR	Mofa	Langsamverkehr Velo	fäG	Fuss	Öffentlicher Personenverkehr Bus	Trolley	Tram	Güterverkehr in Rp / tkm Li	LW	SS
Mio. pkm bzw. tkm													
Grundlage Gesundheit / Gebäude Luft	99'964.8	2'513.3	3'022.5	144.5	2'116.0	113.8	4'894.9	2'573.0	515.3	978.2	1'044.1	7'535.0	9'021.5
Grundlage Lärm	92'313.8	2'600.7	2'389.3	137.7	2'116.0	113.8	4'894.9	2'613.5	536.3	1'018.0	1'097.7	8'094.2	9'691.0
Grundlage Übrige	88'701.6	2'499.0	2'295.8	132.3	2'116.0	113.8	4'894.9	2'511.2	515.3	978.2	1'054.8	7'283.1	8'719.9
Rp. pro pkm bzw. tkm													
Gesundheit Luft	1.0	0.9	0.3	0.4	-	-	-	2.3	n.a.	n.a.	12.4	2.2	1.1
Gebäude Luft	0.2	0.2	0.1	0.1	-	-	-	0.5	n.a.	n.a.	2.5	0.5	0.2
Ernteausfälle Luft	0.0	0.0	0.0	0.0	-	-	-	0.1	-	-	0.6	0.1	0.1
Waldschäden Luft	0.0	0.0	0.0	0.0	-	-	-	0.1	-	-	0.5	0.1	0.1
Biodiversitätsverluste Luft	0.1	0.1	0.0	0.0	-	-	-	0.3	-	-	1.2	0.3	0.1
Lärm	0.7	0.7	10.4	1.2	-	-	-	1.4	0.1	0.1	13.0	2.9	1.4
Klima	1.1	0.4	0.8	0.6	-	-	-	1.0	-	-	8.2	1.3	0.8
Natur und Landschaft	0.7	0.2	0.4	0.4	0.2	0.1	0.1	0.4	0.0	0.0	4.3	0.7	0.4
Bodenschäden	0.1	0.1	0.1	0.1	-	-	-	0.2	0.1	0.0	1.0	0.4	0.2
Vor- und nachgelagerte Prozesse	0.6	0.2	0.4	0.4	0.6	0.4	0.4	0.5	0.4	0.6	4.7	0.8	0.5
Unfälle	0.7	0.1	11.2	44.6	21.3	40.3	7.4	0.1	0.5	0.1	3.2	0.2	0.1
Städtische Räume	0.1	0.0	0.1	0.1	-	-	-	0.1	0.1	0.1	0.9	0.0	0.0
Gesundheitsnutzen Langsamverkehr	-	-	-	-	-18.4	n.a.	-18.2	-	-	-	-	-	-
Total aller Kostenbereiche	5.3	2.8	23.8	47.9	3.7	40.9	-10.3	7.0	1.1	1.0	52.6	9.5	5.0
Abzug LSVA-Anteil	-	0.5	-	-	-	-	-	-	-	-	-	5.2	3.8
Total mit LSVA Abzug	5.3	2.3	23.8	47.9	3.7	40.9	-10.3	7.0	1.1	1.0	52.6	4.4	1.2
Total Teilbereiche		5.7				-5.3			4.8			9.8	
Gesamttotal Sicht Verkehrsart		2.5										4.7	1.4
Gesamttotal Sicht Verkehrsteilnehmende	6.1	2.6	26.3	52.2	4.7	45.1	-10.0	7.5	3.1	1.7	58.3	4.7	1.4
Gesamttotal soziale Kosten	10.7	3.9	70.6	221.9	-73.6	208.9	-135.5	9.4	11.8	4.2	91.3	11.1	5.6

PW = Personenwagen, GW = Gesellschaftswagen, MR = Motorrad, fäG = fahrzeugähnliches Gerät, Fuss = Fussverkehr, Li = Lieferwagen, LW = Lastwagen, SS = Sattelschlepper, n.a. = not available (nicht verfügbar)

Fig. 6 *External costs per t-km per road vehicle type in Switzerland [11]; for the English translation of the cost areas please refer to Fig. 2*

6 EU Tyre Label

One of the instruments in reducing traffic noise is the tyre and therefore the low noise tyres currently available are of particular interest for this project.

The EU tyre label (Fig. 7) available since 2012 and displayed on the tyre in the form of a sticker provides important information about safety and environmental aspects of a tyre. This label allows comparing tyres in terms of fuel efficiency, wet grip and noise. Fuel-efficient tyres are tyres with a lower rolling resistance consuming less energy for friction and heat.

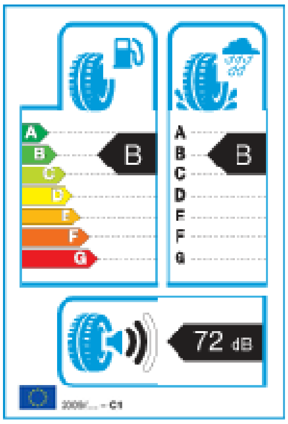


***Fig. 7** Example of the EU tyre label*

Fuel efficiency is rated from A to G on a color-coded scale as follows:
A (green) = highest fuel efficiency rating
G (red) = lowest fuel efficiency rating
Rating D is not used for passenger cars

The difference between an A rating and a G rating could mean a reduction in fuel consumption of up to 7.5%.

Wet grip is another parameter on the EU tyre label. Wet grip refers to the tyre's ability to adhere to the road in wet conditions. The EU rating focuses only on one aspect of wet grip which is the wet braking performance of the tyre.

Wet grip is rated from A to G:
A = highest rating
G = lowest rating

Ratings D and G are not used for passenger cars.

Using the standard test methods set out in Regulation EC 1222/2009, a passenger car applying full brakes from 80 km/h, a set of A-rated tyres will brake up to 18 meters shorter than a set of F-rated tyres. A variation of up to 30% in stopping distance between A and G was measured.

The third parameter on the tyre label is noise. Specifically, the amount of pass-by noise a vehicle generates.

Since many people are unfamiliar with decibel values, the noise class is also shown. This categorizes the tyre in relation to forthcoming European tyre noise limits.

1 black wave: Quiet (3 dB or more below the European limit of 72 that is 69 dB or below)

2 black waves: Moderate (between the future European limit of 72 dB and 69 dB)

3 black waves: Noisy (above the future European limit of 72 dB)

Decibel levels are measured on a logarithmic scale For example, a difference of 3 dB doubles the power of external noise the tyre produces as demonstrated in Fig. 8.

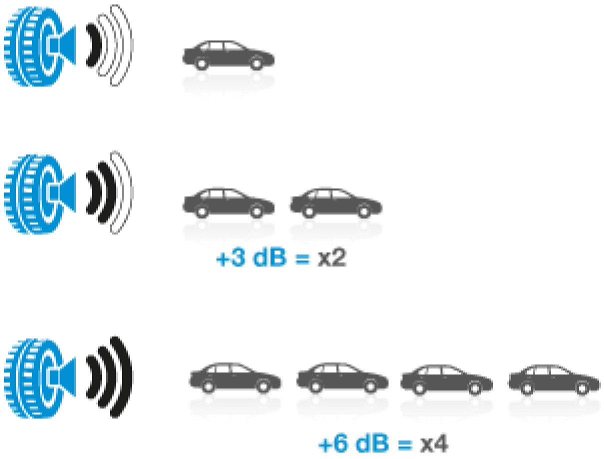


***Fig. 8** Demonstration of the effect of 3 dB increase in noise emissions (http://www.goodyear.eu/home_en/goodyear-quality/eu-tyre-label/index.jsp#noise accessed 9.9.2014).*

6.1 Properties of new tyres from ReifenDirekt.ch

As demonstrated in Fig. 9, Truck tyres are differentiated according to the type of axle they are mounted on: driving axle tyres; front axle tyres and trailer tyres.

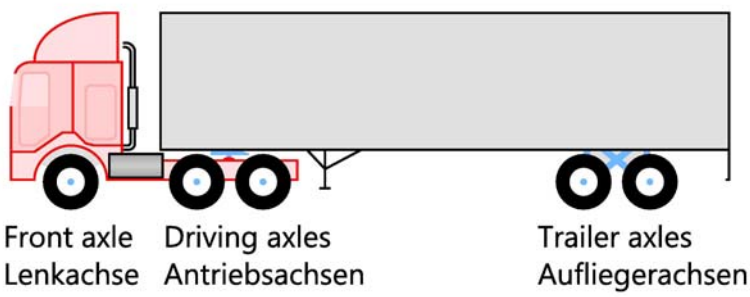


***Fig. 9** Different axles, requiring different tyres, on an articulated vehicle.*

In order to create an overview of the noise properties of new tyres, the database of a large online vendor: http://www.reifendirekt.ch/LKW-Reifen.html was evaluated here as shown in the following sections (data download August 2014). This database is created by the tyre manufacturers using a standardized pavement for the acoustic measurements. From the database the information of 300 driving axle tyres, 200 front axle tyres and 30 trailer tyres was extracted. The average noise values are shown in ***Tab. 3***. As can be seen, there is a significant difference of approximately 3 dB(A) between driving axle tyres on the one hand and front axle and trailer tyres on the other hand. As discussed above this corresponds to doubling or halving the noise emissions. The seasonal differences are not that prominent and can be neglected as a first approximation.

Tab. 3 *Average tyre noise values in dB(A) for the different axle types, differentiated according to the seasonal use.*

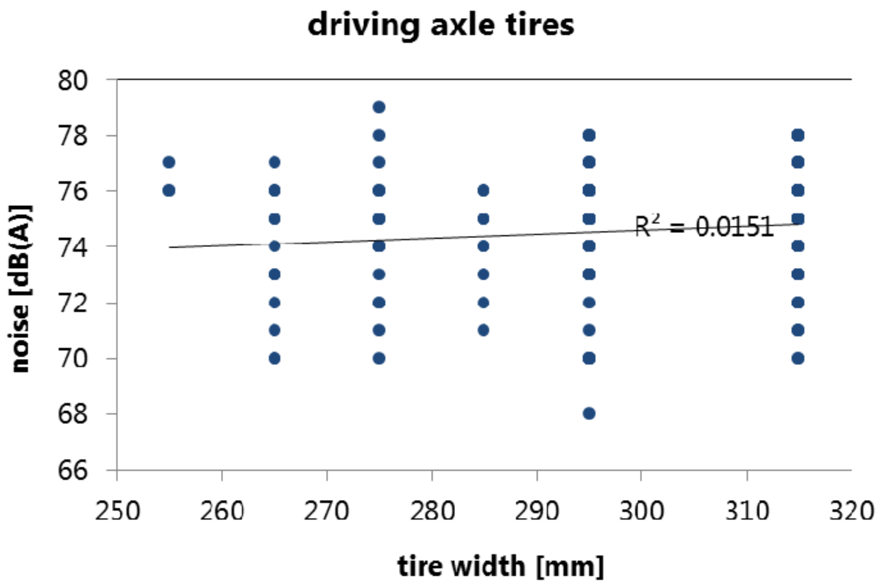
	all season	summer	winter	total
driving axle	74.7	74.6	74.2	74.6
front axle		71.5	73.0	71.6
trailer	72.0	71.1		71.3

Tab. 4 shows the variances, obtained for the three sets of different tyre types. If no information is available about the tyre type, these values represent the unavoidable uncertainty of any model to predict the emission of a specific vehicle.

Tab. 4 *Variance of the tyre noise values in dB(A) for the different axle types*

	variance
driving axle	3.4
front axle	3.8
trailer	4.3

In the following, correlations between different tyre parameters are investigated. As Fig. 10 reveals, there is no significant relation between noise and tyre width. From Fig. 11 it can be seen, that the load index, that refers to the maximum carrying capacity, highly positively correlates with tyre width (wide tyres can carry heavier loads).



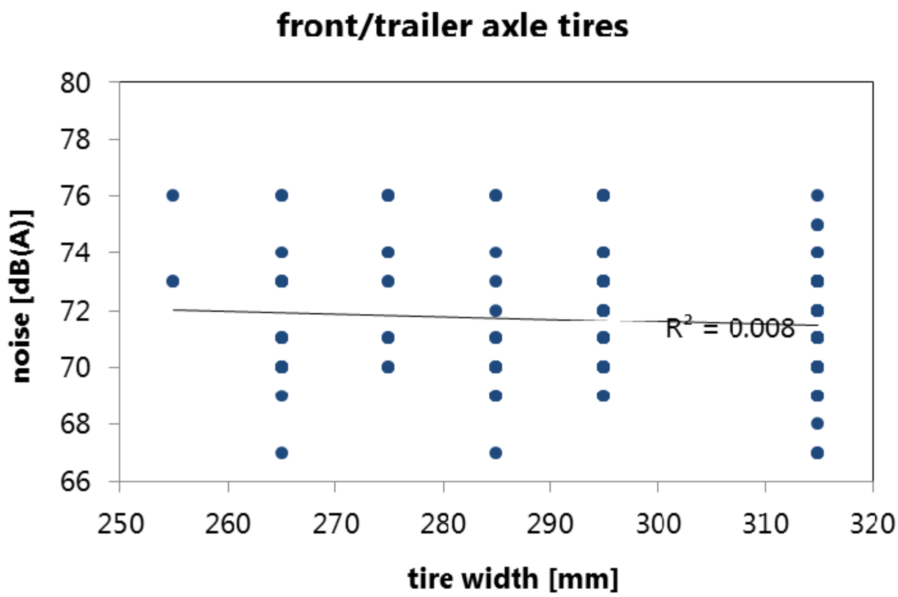
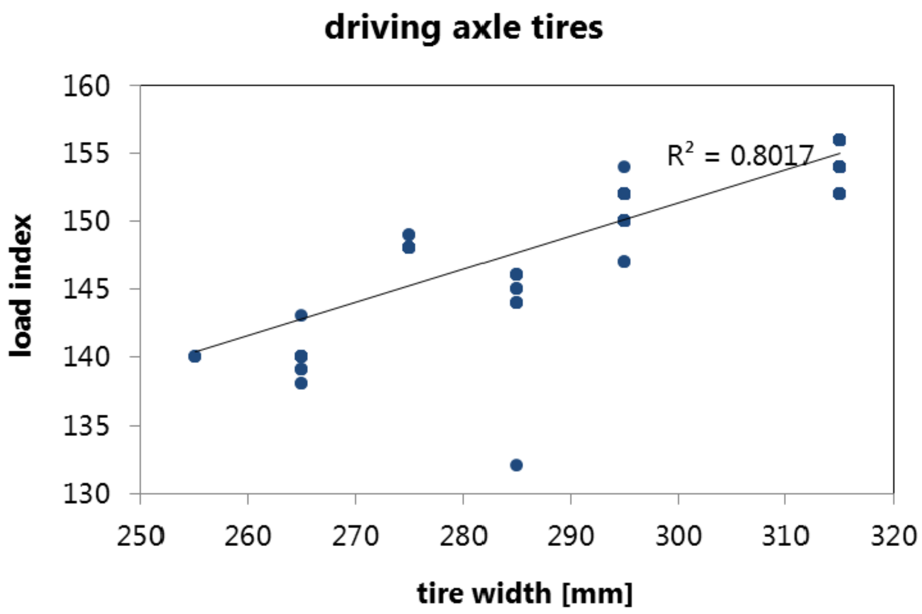


***Fig. 10** xy-plot of tire noise and tire width for driving axle (top) and front/trailer axle (bottom) tires.*



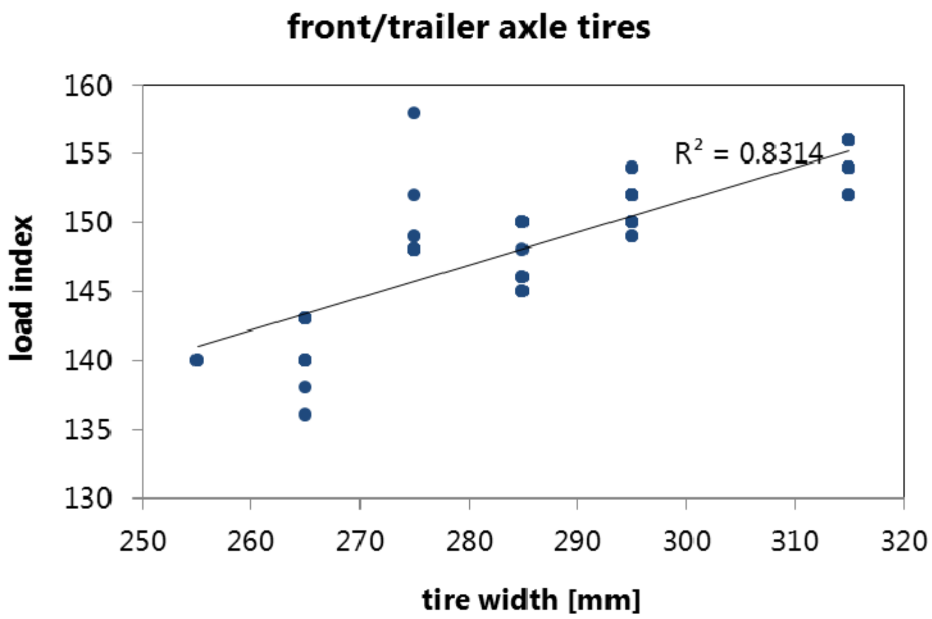


***Fig. 11** xy-plot of the load index and tire width for driving axle (top) and front/trailer axle (bottom) tires.*

6.2 Summary of findings

- The EU tyre label provides a means to evaluate tyres from the point of view of noise and to encourage low noise tyres
- No significant difference in summer and winter tyres was seen
- Driving axle tyres are more noisy than front and trailer tyres
- The variance in the tyres (>3 dBA) shows that there is a great potential to lower traffic noise by using low noise tyres

7 Swiss Road Transport Performance

Data provided by the Swiss Federal Customs Administration (FCA/EZV) indicates that the transport performance that is the number of tonnes and kilometres transported in Switzerland by road has stayed relatively constant from 2007 to 2014. The value has remained between 65 to 69 bio t-km total per year, as indicated in Fig. 12. This data is calculated assuming that the HDVs are fully loaded as opposed to the actually carried weight.

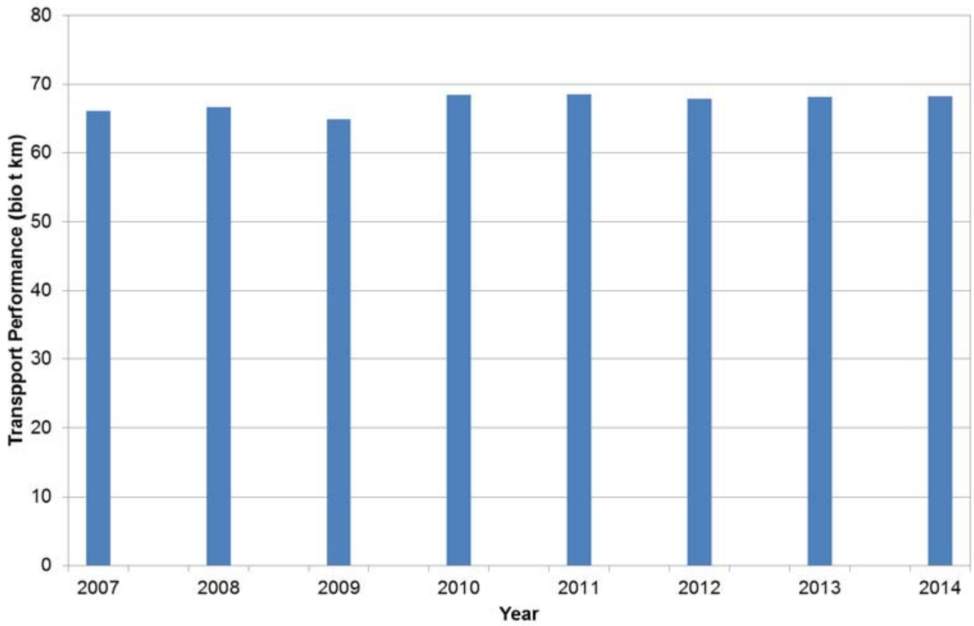


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***Fig. 12** Road freight transportation performance in Switzerland from 2007 until 2014. Data courtesy of Federal Customs Administration (FCA/EZV)*

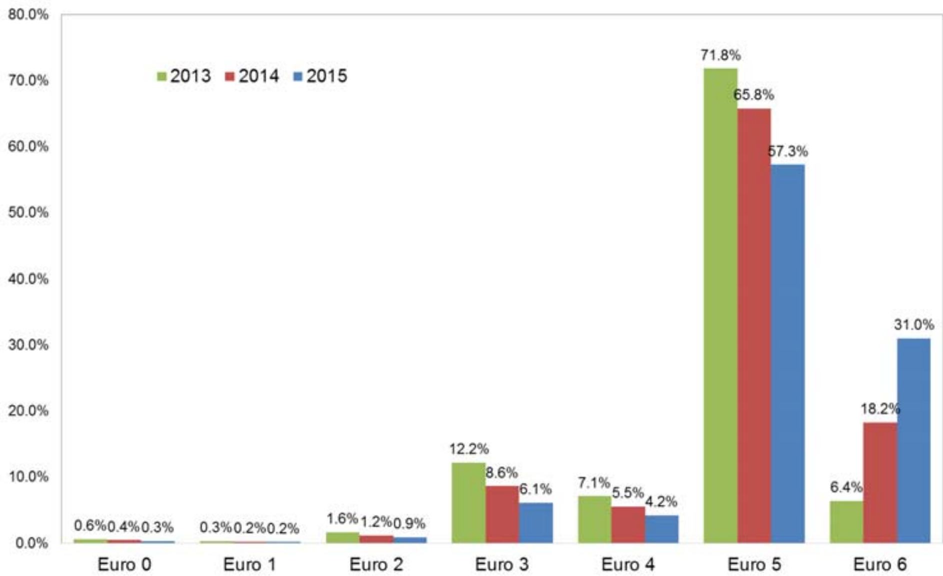


***Fig. 13** Distribution of road transport performance in Switzerland according to EURO emissions classes in the fourth quarter of 2013, 2014 and 2015. Data courtesy of Federal Customs Administration (FCA/EZV)*

Looking at a sample of the data for 2013, 2014 and 2015 (Fig. 13 and Tab. 5) shows that the EURO V vehicles transport the most tonnage with the clear trend being an increase in EUROVI vehicles.

***Tab. 5** Distribution of road transport performance in Switzerland according to Euro emissions classes in 2014 and 2015. Data courtesy of federal customs administration (FCA/EZV)*

Quarter-Nr.: 1	2014	
Euro class	**Tonne-kilometer**	**Percent**
Euro 0	61'469'595	0.4%
Euro 1	34'830'980	0.2%
Euro 2	196'352'176	1.2%
Euro 3	1'662'386'039	10.4%
Euro 4	1'050'189'455	6.6%
Euro 5	11'531'864'262	72.4%
Euro 6	1'398'933'226	8.8%
Total	**15'936'025'733**	**100%**

Quarter-Nr.: 2	2014	
Euro class	**Tonne-kilometer**	**Percent**
Euro 0	87'852'009	0.5%
Euro 1	44'424'521	0.3%
Euro 2	238'620'962	1.4%
Euro 3	1'823'732'501	10.4%
Euro 4	1'114'532'336	6.3%
Euro 5	12'234'067'637	69.5%
Euro 6	2'058'438'617	11.7%
Total	**17'601'668'583**	**100%**

Quarter-Nr.: 3	2014	
Euro class	**Tonne-kilometer**	**Percent**
Euro 0	86'694'891	0.5%
Euro 1	43'211'971	0.2%
Euro 2	225'226'837	1.3%
Euro 3	1'669'895'979	9.4%
Euro 4	1'031'586'383	5.8%
Euro 5	11'943'471'205	67.5%
Euro 6	2'688'566'099	15.2%
Total	**17'688'653'365**	**100%**

Quarter-Nr.: 4	2014	
Euro class	**Tonne-kilometer**	**Percent**
Euro 0	74'917'652	0.4%
Euro 1	38'541'274	0.2%
Euro 2	195'343'896	1.2%
Euro 3	1'458'555'265	8.6%
Euro 4	935'840'807	5.5%
Euro 5	11'139'703'222	65.8%
Euro 6	3'089'682'593	18.2%
Total	**16'932'584'709**	**100%**

Quarter-Nr.: 1	2015	
Euro class	**Tonne-kilometer**	**Percent**
Euro 0	47'574'213	0.3%
Euro 1	26'255'256	0.2%
Euro 2	140'701'067	0.9%
Euro 3	1'140'350'417	7.3%
Euro 4	789'234'621	5.0%
Euro 5	10'089'415'416	64.5%
Euro 6	3'409'474'708	21.8%
Total	**15'643'005'698**	**100%**

Quarter-Nr.: 2	2015	
Euro class	**Tonne-kilometer**	**Percent**
Euro 0	69'323'869	0.4%
Euro 1	35'758'771	0.2%
Euro 2	181'729'997	1.0%
Euro 3	1'305'695'878	7.5%
Euro 4	863'735'148	4.9%
Euro 5	10'799'971'822	61.6%
Euro 6	4'267'460'930	24.4%
Total	**17'523'676'415**	**100%**

Quarter-Nr.: 3	2015	
Euro class	**Tonne-kilometer**	**Percent**
Euro 0	67'961'015	0.4%
Euro 1	33'055'424	0.2%
Euro 2	167'690'882	0.9%
Euro 3	1'201'911'667	6.8%
Euro 4	802'203'178	4.5%
Euro 5	10'508'130'170	59.3%
Euro 6	4'937'893'025	27.9%
Total	**17'718'845'361**	**100%**

Quarter-Nr.: 4	2015	
Euro class	**Tonne-kilometer**	**Percent**
Euro 0	55'015'372	0.3%
Euro 1	30'360'973	0.2%
Euro 2	146'033'532	0.9%
Euro 3	1'039'897'284	6.1%
Euro 4	715'462'638	4.2%
Euro 5	9'719'629'322	57.3%
Euro 6	5'264'230'561	31.0%
Total	**16'970'629'682**	**100%**

8 Relating environmental impact of vehicle classes within the LSVA framework to costs

In order to identify how to best internalize costs from road freight transport through a new version of the LSVA, it was first necessary to understand how the costs might be linked to the different transport technologies currently on the road. Since, to a good extent, the costs are caused by the environmental impacts bound to the emissions of the vehicles, a first step was to identify how to relate costs to specific engine emissions. In order to do so, a method compatible with the data availability of the LSVA framework for estimating and comparing the environmental impacts of different transport vehicles was developed.

8.1 Data

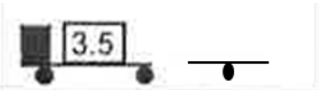
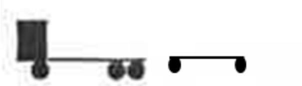
The data used for the calculations presented in this chapter were obtained from the WIM and LSVA monitoring site at Oberbuchsiten that was combined with a microphone for the noise measurements as explained in detail elsewhere [13]. The data was obtained in March, September and November 2011. 350'000 vehicles were analyzed going through the following method to improve data quality as developed in the Footprint III project [13]. The data quality was improved by excluding some data in the calculations of the total Eco Points (Umweltbelastungspunkte or UBP) and total cost as shown in Tab. 6 as discussed later.

Tab. 6 *Data quality improvement strategy (GVM=Gross Vehicle Mass)*

Item	Data not incorporated in the analysis	Reason
1	GVM=0	Error in WIM data
2	GVM=99999	Special vehicle which has most likely paid for a special permit
3	GVMallowed=0	No LSVA Data ex. Bus
4	Nr. Axles>5	Not common in Switzerland. Mostly special vehicles or WIM error
5	WIM Speed< 70 km/h	Not freely moving traffic , not optimal for noise measurements
6	Lp=-99.9	Noise data is not valid
7	EUROVI	EURO VI vehicles were not on the road in 2011 therefore this is considered as a mistake in the data
8	GVM>40t	This is either due to error in WIM data or oversized vehicles with a special permit that are not considered here

Tab. 7 shows the number of vehicles in each SWISS10 vehicle category, identified also with its silhouette. As shown a total of 288'000 vehicles were analysed with Swiss category 10 being the majority with 43% followed by category 9 with 27% and category 8 with 21%.

Tab. 7 *Number of vehicles in each Swiss 10 vehicle category used in the data analysis*

Veh silhouette	Veh Category	Number of Vehicles	%
	SWISS10-1	9‘998	3
	SWISS10-5	5‘413	2
	SWISS10-6	1‘460	1
	SWISS10-7	8‘487	3
	SWISS10-8	59‘606	21
	SWISS10-9	79‘197	27
	SWISS10-10	124‘047	43
	All Veh Cat.	288208	100

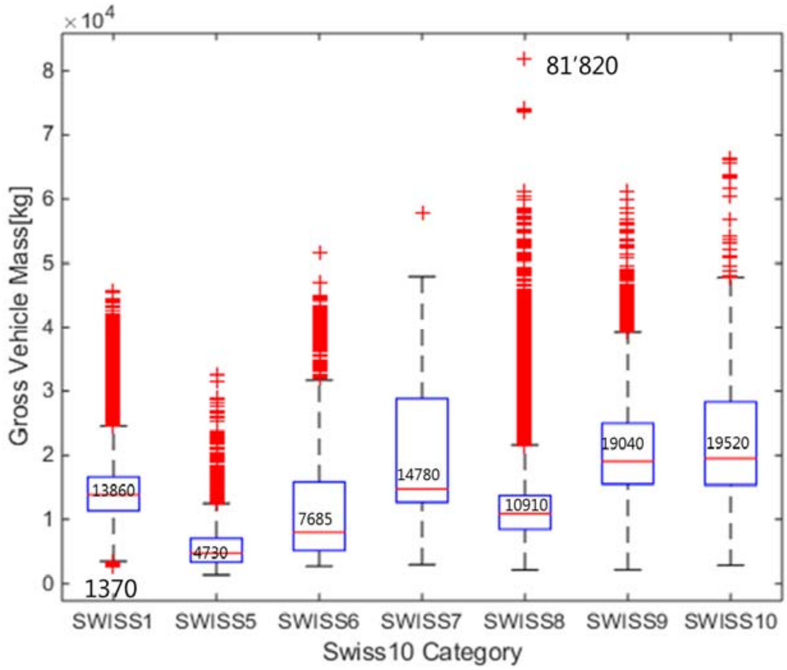


Fig. 14 *Box plot showing the distribution of gross vehicle mass (GVM) in the data set. The median value for each SWISS 10 vehicle category as well as the maximum and minimum values measured are also shown.*

Fig. 14 shows the distribution of gross vehicle mass from the WIM data. In addition the highest recorded value is shown that was for a class 8 vehicle at 81'820 kg as well as the lowest value of 1'370 for a class 1 vehicle. Fig. 15 shows the recorded maximum pass by noise level for Swiss 10 heavy vehicle categories as well as the maximum value of 110.4 dB(A) recorded for a class 10 and minimum of 60.6 dB(A) for a class 8 vehicle.

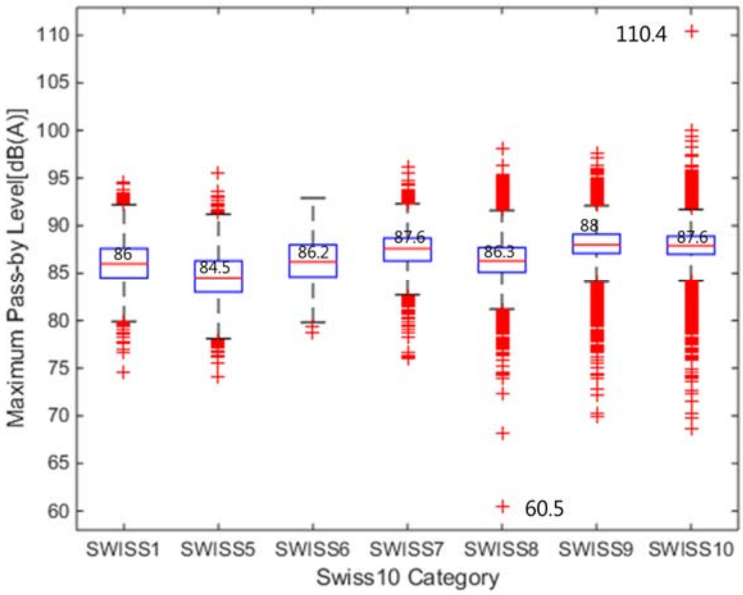


***Fig. 15** Box plot showing the distribution of maximum pass-by noise level in the data set. The median value for SWISS 10 heavy vehicle categories as well as the highest and lowest recorded values are also shown.*

8.2 The ecological scarcity method (Eco-points)

The ecological scarcity method allows comparing the different environmental factors used in this project. In general, the method allows assessing the impact of pollutant emissions and resource extraction activities on the environment (impact assessment) as part of a life cycle assessment. The key metrics of this method are eco-factors, which measure the environmental impact of pollutant emissions or resource extraction activities in Eco-points (EP=UBP) per unit of quantity. The main advantage of this method is that UBPs from very different sources can be added and/or compared [28]. To this end this method could be used to compare the noise and pollutant effect that were part of the data base available. In terms of emissions, the key information is the EURO norm which defines the maximum allowed emissions of 4 pollutants: HC, CO, NOx and PM. Here, the ecological scarcity method [28] was used to quantify and compare the environmental impacts of the different EURO classes.

8.2.1 Pollutant emissions and their conversion to Eco-points and cost

Pollutant emissions of heavy duty engines are limited. Since heavy duty engines are used in very different applications, there are no limits for a vehicle (in g/km) over a regulated driving pattern but there are limits set for the engine over a regulated test procedure in g/kWh mechanical work on an engine test bench. The European heavy duty engine legislation was massively tightened since it was introduced in the 1990s. Not only the emission limits were tightened but also the test procedure was modified several times. The test cycles, in which the emissions are measured an engine test benches, have changed significantly over the years. Up to EURO II the test cycles were stationary. From EURO III additionally transient (dynamic) cycles were added and emissions were also limited in these transient cycles. From EURO VI cold start was introduced (earlier the engines would be warmed up first). Besides the classical pollutant emissions (mainly NOx and PM), also particle number emissions (PN) were limited with Euro VI. This made it necessary, to use highly efficient wall-flow particle filter technologies. Furthermore, with EURO VI, the engine does not only have to fulfil emission limits in the test cycles on the engine test bench but it has also to show that the so-called off-cycle emissions are within limits, i.e. the engine can be driven in any point within the so called control area and the pollutant emissions have to stay within the so-called not-to-exceed (NTE) limits. In addition to that Euro VI also introduced in-use testing where the manufacturer has to show, with instrumented vehicles driving on the road, that the engine emissions stay within the limits plus the durability has to be proven over 7 years or 700'000 km. In summary, engines for heavy duty vehicles have made significant developments over the last decades and that EURO VI engines, which are today's current legislation, are extremely low-polluting, under test conditions and in real-world operation. The question to be addressed here is what this development means in terms of external costs. To compare very different sources for external costs, the ecological scarcity method using Eco Points (UBP) is used [28]. As a basis for the quantification, the evolution of emission limits is used and the contributions of NOx and diesel soot are considered. One problem is that the chemical composition of particle emissions is highly complex, only one part is soot. From combustion, about 41% can be estimated to be soot according to Guan et al. [30]. What the mass composition of particles after a particle filter will be, is unknown. It is quite impractical to sample such small amounts of particle emissions in a manner that the mass of individual components can be determined. Therefore, three cases are considered for EURO VI technology: One worst case assuming the unrealistic situation that all particle mass consists of soot, one medium case assuming that also after a particle filter 41% of the particle mass is soot and one best case assuming that no soot at all is emitted after the exhaust has passed through a particle filter. A realistic case could be between the medium and the best case as it is very likely that soot is oxidized in a particle filter and the share of soot leaving a filter is very small. ***Tab. 8*** shows the resulting UBPs, the UBPs from NOx and soot was taken from [28]. The Euro Norm also regulates HC and CO. UBP coefficients for these are also available; however these emissions are very small in comparison and negligible for the calculations performed here.

Tab. 8 *Calculation of Eco Points / kWh for EURO vehicles categories*

							UBP NOx 39 [UBP/g]	UBP soot 38000 [UBP/g]	
EURO Cat.	**test cycle**	**Trans cycle**	**+ cold start**	**NOx limit [g/kWh]**	**PM limit [g/kWh]**	**share of soot in PM**	**UBP NOx [UBP/kWh]**	**UBP PM [UBP/kWh]**	**UBP total [UBP/kWh]**
I	ESC R-49			8.00	0.36	41%	312	5609	5921
II	ESC R-49			7.00	0.25	41%	273	3895	4168
III	ETC	X		5.00	0.16	41%	195	2493	2688
IV	ETC	X		3.50	0.03	41%	137	467	604
V	ETC	X		2.00	0.03	41%	78	467	545
VI (worst case)	WHTC	X	X	0.40	0.01	100%	16	380	396
VI (real)	WHTC	X	X	0.40	0.01	41%	16	156	171
VI (best case)	WHTC	X	X	0.40	0	0%	16	0	16

Assuming that different engines have to deliver the same amount of mechanical work [kWh] to cover the same distance, one can directly compare the UBP values of the different engine technologies. If UBP/km is needed, a typical energy demand W [kWh/km] to cover a certain distance must be assumed. The simplest way to do this is to estimate a typical fuel consumption V [l/km] and a typical average engine efficiency η as shown in the equation below:

$$W = V * \rho * H * \frac{1}{3.6} * \eta$$

Where, ρ is the fuel density (typically 0.84 kg/l for diesel fuel) and H is the fuel's lower heating value (typically 43 MJ/kg). Fuel consumptions V can e.g. be found in [http://www.hbefa.net/e/documents/HBEFA32_EF_Euro_5_6_TUG.pdf -> Figure 44]. Typical heavy duty engines have peak efficiencies in the range of 44-46%. Real-world driving efficiencies are slightly lower; one can assume 42% for a typical diesel engine. As an example, for an average mission, mechanical energy demand of 1.26 kWh/km results in an assumed fuel consumption of 30 l/100km (0.3 l/km). This leads to distance-specific UBPs from gaseous emissions as follows shown in ***Tab. 9***:

At the same time the highest average cost per driven km for heavy vehicles was given in Fig. 5 and ***Tab. 17*** to be 11.4 CH cents (Rappen) per km. For the purpose of brevity the average of the higher costs were used in the calculations. Considering that this is the cost of the average truck, this value was assigned to the median UBP (545) as calculated in ***Tab. 9***: and the other vehicle pollutant emissions were calculated proportionally using the equation below:

$$Cost_{pol} = 11.4 * \frac{UBP_i}{UBP_{median}}$$

Were UBPi is the UBPs for a particular vehicle with a particular engine category and the UBP $_{median}$ is the mean UBP for all categories. ***Tab. 9*** shows how a vehicle with the best engine in terms of pollutants can cost 0.33 Rappens per km whereas a EUROI engine can costs 123.85 Rappen per km. In the calculations the same values as EUROI was assigned to EURO0.

Tab. 9 *Eco Points/driven km, and Cost /driven km per EURO vehicle category due to emissions*

EURO Cat.	UBP total [UBP/km]	Cost [Rp/km]
I	5921	123.85
II	4168	87.18
III	2688	56.23
IV	604	12.63
V	545	11.40
VI (worst case)	396	8.28
VI (medium)	171	3.58
VI (best case)	16	0.33

Fig. 16 and Fig. 17 show the distribution of the Eco Points and costs due to the vehicles emissions category obtained from the data set respectively, the median for each as well as the maximum and minimum values are shown.

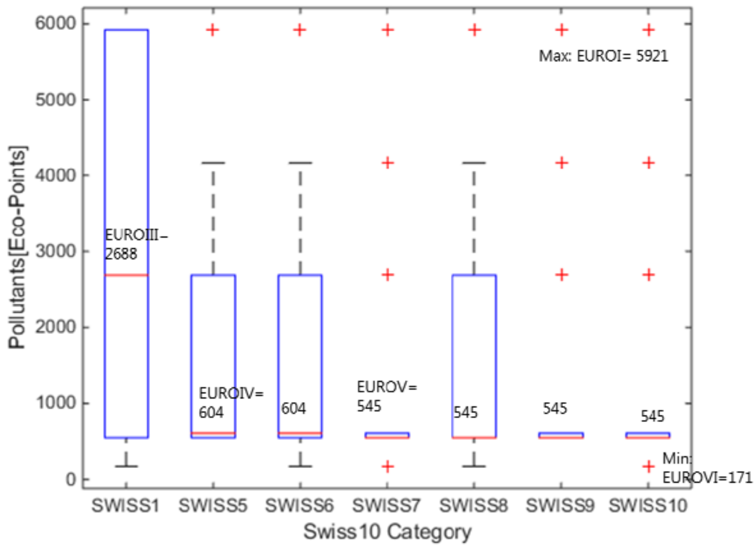


Fig. 16 *Box plot showing the distribution in the data set of Pollutant emissions for SWISS 10 vehicle categories using Eco Points (UBPs). The median value for SWISS 10 heavy vehicle categories as well as the highest and lowest recorded values are also shown.*

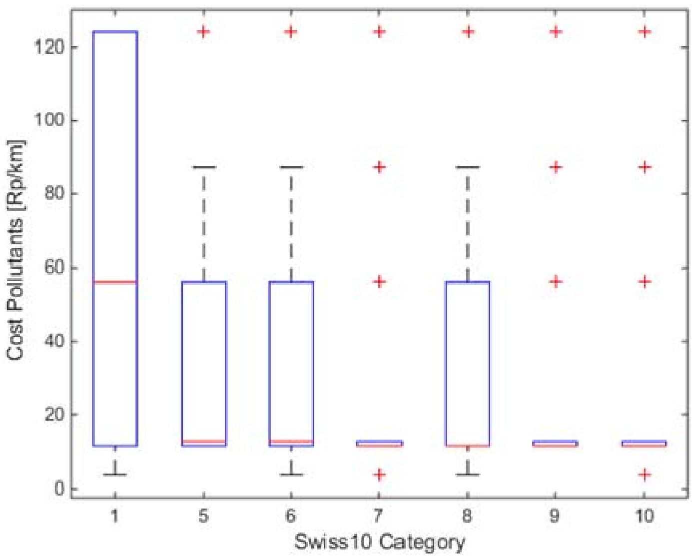


Fig. 17 *Box plot showing the distribution of costs of Pollutant emissions for SWISS 10 heavy vehicle categories*

The data indicates that vehicle categories 7, 9 and 10 incur the lowest pollutants as well as external costs due to pollutants.

8.2.2 Noise and the conversion to Eco Points and costs

From the ecological scarcity method the Eco Points (UBP) for noise generated by an average truck is calculated to be 210/km [28]. Using this value for an average truck and the data set from the footprint monitoring site, the corresponding UBP's for all vehicles were calculated considering that ±3dB corresponds to doubling or halving of the noise, so the UPB's were doubled when the measured pass by noise was 3dB higher than the median.

At the same time the cost per driven km due to noise was given in ***Tab. 17*** to be 15 CH cents (Rappen) per km. Assuming that this is the cost of the average truck, this value was assigned to the median of category eight or higher and the other vehicle noise emissions were calculated proportionally using a logarithmic scale as shown in the equations below:

$$UPB_{noise} = 210 * 10^{(0.1*(x - x_{mean}))}$$

$$Cost_{noise} = 15 * 10^{(0.1*(x - x_{mean}))}$$

Where, x is the maximum pass by noise level in dB(A) of the individual vehicle and x_{mean} is the mean maximum pass by noise level in dB(A) of classes 8 and up (as the 210 UPBs are assigned to the heavy vehicles) in the data set. Fig. 18 shows the distribution of cost of noise for each Swiss 10 vehicle category. The lowest median cost was 13.0 Rp/km for category 1 and the highest was for category 10 at 14.66 Rp/km. However, as seen in Fig. 15 and Fig. 18 in every vehicle category there are many that are above the median. Similar trend is seen for the UPB's due to noise.

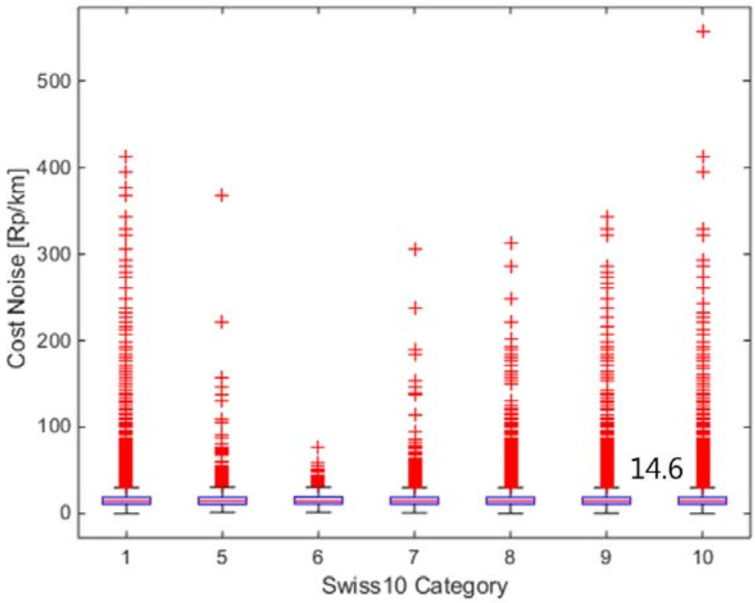


Fig. 18 *Distribution of cost due to noise in Rappen/ km for Swiss 10 heavy vehicle categories*

8.2.3 Dynamic Load and conversion to Eco Points and cost

As the UBP's were not available for infrastructure damage, in this case the costs/tkm was used as a basis for comparison of the data. According to the external cost report [11] the infrastructure damage costs were calculated to be 400 Mio CHF. According to the data from the Swiss tolling office the transport performance was ca. 69 Bio tkm in 2014 (Fig. 12). Therefore the external cost of infrastructure damage can be calculated to be 0.58 Rp/tkm as shown in ***Tab. 10***.

***Tab. 10** Calculation of external cost of infrastructure damage per tkm*

Uncovered Infrastructure costs [CHF]	4.00E+08
Swiss transport performance [t-km]	6.90E+10
External costs of infrastr damage/tkm [CHF/tkm]	5.80E-03
External cost of infrastr damage/tkm [Rp/tkm]	0.58

In order to calculate the individual vehicle portion of the external infrastructure costs the external cost per t-km as calculated from ***Tab. 10*** was multiplied by the tonnage carried by each vehicle in the data set as shown below.

$$Cost_{load} = 0.58 * T_i$$

Were, T_i is the maximum gross vehicle weight in tonnes carried by the particular vehicle from the weigh-in-motion data. The distribution of costs for each Swiss 10 vehicle category is shown in Fig. 19. It can be seen that the average cost of the vehicles per kilometer varies between 3 and 12 Rappen per kilometer.

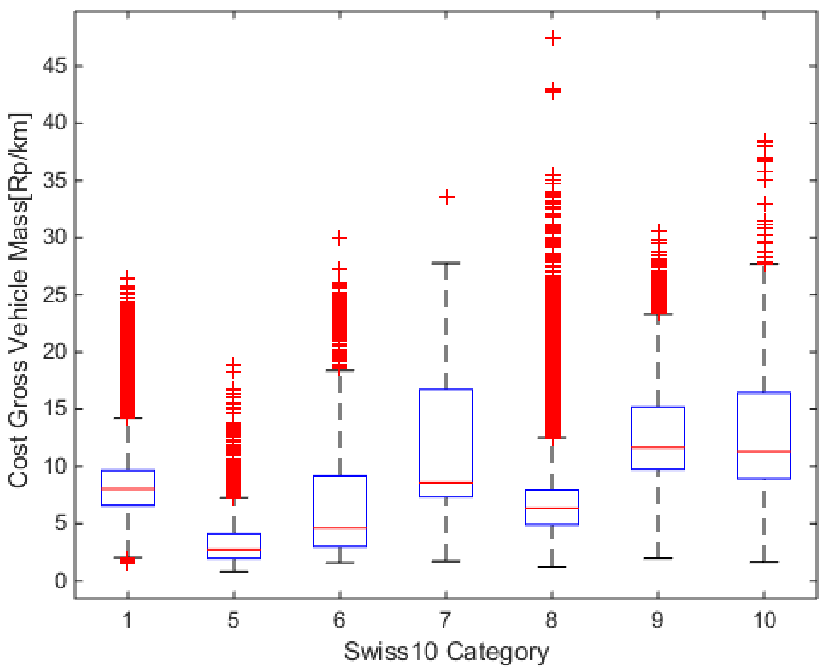


***Fig. 19** Box plot showing the distribution of external cost due to the mass of the Swiss 10 heavy vehicle categories*

8.2.4 Total Eco Points for pollutants and noise

In order to calculate the total Eco Points per vehicle, the UBPs for pollutant emissions calculated in ***Tab. 9*** were directly added to the UPBs calculated for noise as shown in the equation below. The distribution for each vehicle category is shown in Fig. 20. It can be seen that the mean Eco-points for the various vehicle categories do not vary significantly (except for vehicle category 1) however the most significant difference is the variance in each category as can be seen in the figure with the size of the box. Furthermore the data shows that in each category there are vehicles with a very high environmental footprint indicating the potential for improvement.

$$TotalUBP_i = UBP_{noise,i} + UBP_{poll,i}$$

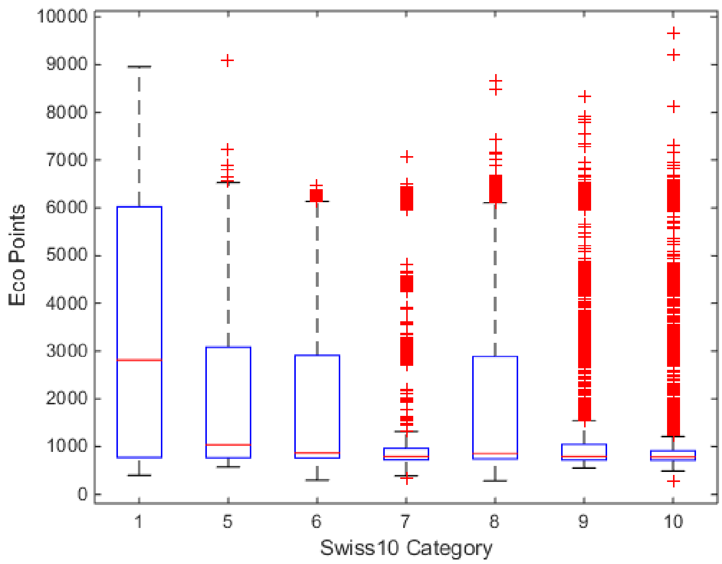


Fig. 20 *Total Eco-Points for Swiss 10 heavy vehicle categories*

8.2.5 Total Costs for infrastructure damage, noise and pollution

The total cost of each vehicle i was calculated by adding all the individual costs as follows:

$$TotalCost_i = Cost_{load,i} + Cost_{noise,i} + Cost_{poll,i}$$

The distribution of the costs for each vehicle category is shown in Fig. 21. It can be seen that regarding cost per km in every category there are vehicles that cause higher costs than the median for that category showing the great potential to encourage those vehicles to be more environmentally friendly.

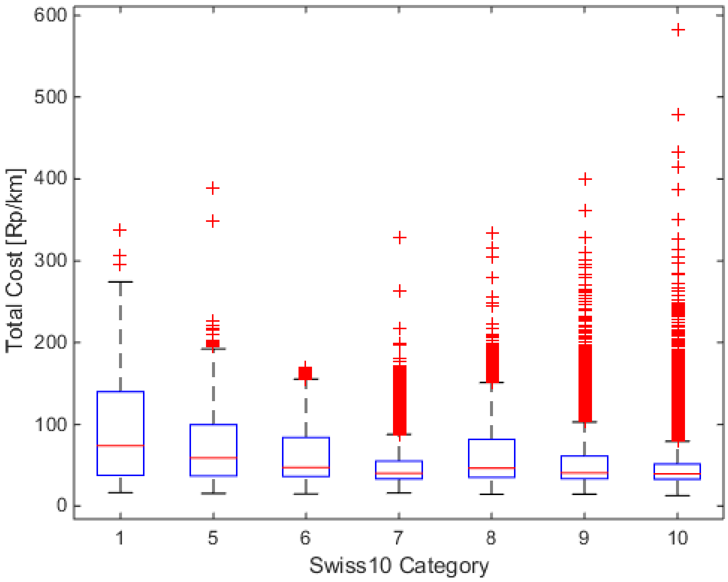


***Fig. 21** Total costs for Swiss 10 heavy vehicle categories*

9 Noise Emission Model for Vehicle Categories

9.1 Relevant Model Parameters

In order to identify the relevant parameters to characterize the noise emission of a single vehicle, the noise data obtained at the Oberbuchsiten site in 2011 are re-evaluated under the assumption that the following information is available:

- Vehicle category according to the Swiss10 classification scheme
- Number of axles
- Maximum allowable weight

Based on the information available, three different emission models shown below are tested to predict the maximum noise level of an individual vehicle as measured in Oberbuchsiten. For the comparison, all the measurements were normalized for a vehicle speed of 80 km/h assuming a 30·$Log_{10}(v)$ speed dependency.

- Model 1: only the vehicle category is considered
- Model 2: the vehicle category and number of axles are taken into account
- Model 3: the vehicle category, the number of axles and the maximum allowable weight is considered

The analysis of the emission of tyres for heavy vehicles in section 6, yielded that driving axle tyres are typically 3 dB(A) louder compared to front axle or trailer tyres. As discussed in section 6 an addition of 3 dB(A) means doubling the sound emissions, i.e. the driving axle is emitting double the other axles. In order to represent this in the model this increase in noise is represented by adding one more axle. Therefore in models 2 and 3 the number of axles is incremented by 1 with respect to the axles that are physically present. It should be noted that some vehicles may have more than one driving axle, but this is ignored here.

With n: number of physically present axles and w_a the maximum allowable weight, the three models predict the maximum pass-by level L_{max} of a vehicle of SWISS10 category i at 80 km/h as:

Model1 :

$$L_{\max,80km/h,,i} = A_i$$

Model 2:

$$L_{\max,80km/h,i} = A_i + E_i \cdot Log_{10}(n+1)$$

Model 3:

$$L_{\max,80km/h,i} = A_i + D_i \cdot w_a + E_i \cdot Log_{10}(n+1)$$

For the three models the parameters A_i, D_i and E_i were adjusted for minimal mean squared differences with respect to the measurements. Fig. 22 shows the resulting model errors. As can be seen, the noise emission of vehicles in categories 9 and 10 is already accurately predicted by model 1. Taking into account the number of axles and the allowable weight does not significantly reduce the error. The remaining variance can be attributed to the unknown emission properties of the tyres. On the other hand, for categories 6, 7 and 8, models 2 and 3 clearly outperform model 1. With respect to the relevance in predicting the emission of a single vehicle, the following ranking list can be given:

1. Vehicle category
2. Number of axles
3. Maximum allowed weight

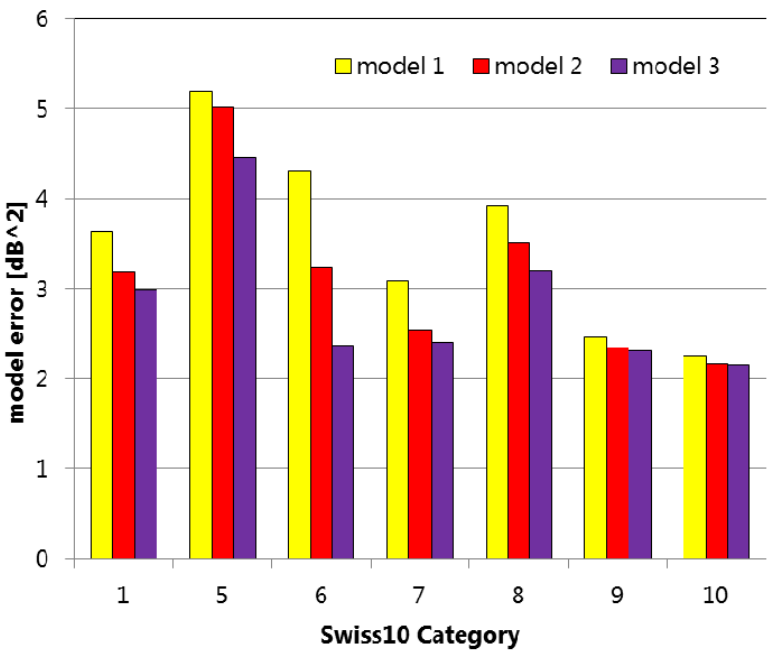


Fig. 22 *Model errors as average squared differences between prediction and measurement for the SWISS 10 categories 1 and 5 to 10.*

9.2 Noise Emission Model

9.2.1 Model for a highway speed regime

At speeds of 80 to 90 km/h that is relevant for the data set used here, the acoustical emission is dominated by tyre noise whereas the engine noise component plays only a minor role. The measurement at Oberbuchsiten and the corresponding models can be regarded as representative for a highway speed regime. For the three emission models introduced above, the following optimal parameter values were found:

Model1 :

$$L_{\max,80km/h,i} = A_i$$

.

Tab. 11 *Optimal parameter setting in Model 1*

SWISS-10 category	A_i
1	87.1
5	85.2
6	86.8
7	87.8
8	86.7
9	88.3
10	88.2

Model 2:

$$L_{\max,80km/h,i} = A_i + E_i \cdot Log_{10}(n+1)$$

Tab. 12 *Optimal parameter setting in Model 2.*

SWISS-10 category	A_i	E_i
1	83.2	7.0
5	80.4	10.0
6	80.0	10.0
7	82.6	7.6
8	82.4	8.4
9	82.8	7.6
10	84.4	5.2

Based on the Oberbuchsiten data from 2011, a statistics was established to identify the number of axles within a SWISS10 category (Fig. 23). Fig. 24 shows the number of vehicles as a function of the noise emission level delta according to the number of axles making usage of Model 2.

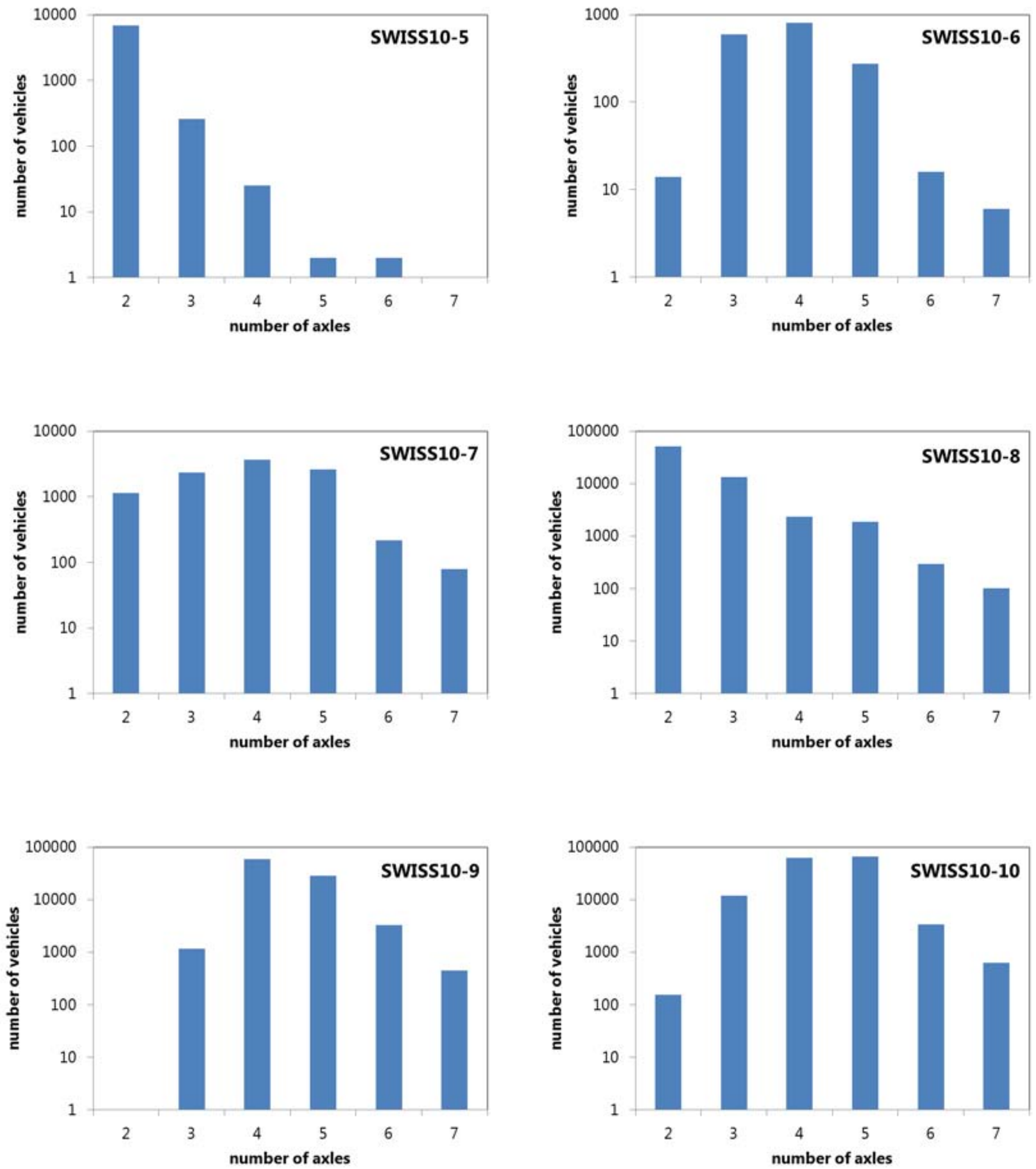


Fig. 23 *Histograms showing the number of vehicles with a certain number of axles in SWISS10 categories 5 to 10*

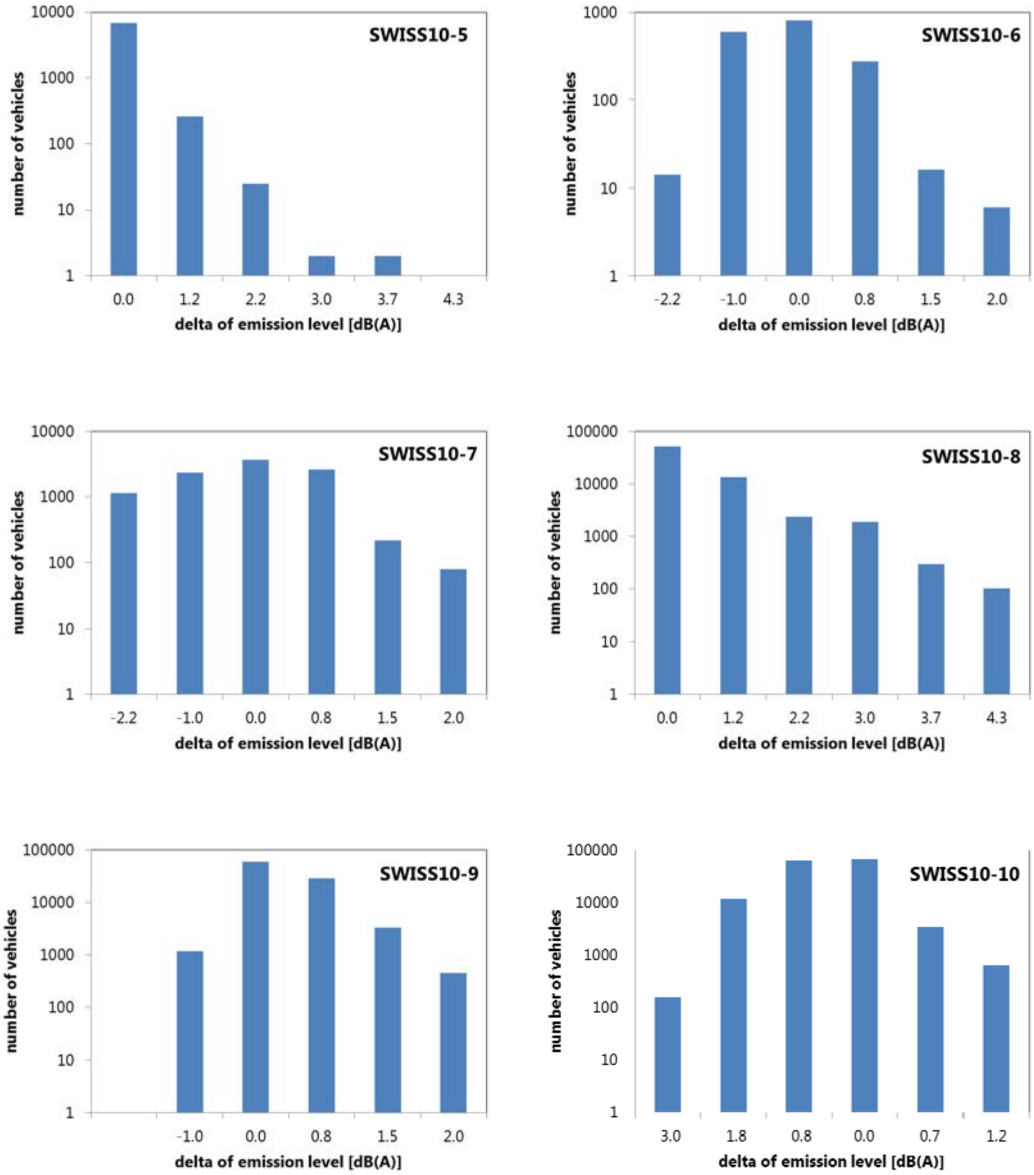


***Fig. 24** Histograms showing the number of vehicles with a certain noise emission level difference according to the number of axles in SWISS10 categories 5 to10.*

Model 3:

$$L_{\max,80km/h,i} = A_i + D_i \cdot w_a + E_i \cdot Log_{10}(n+1)$$

Tab. 13 *Optimal parameter values in Model 3.*

SWISS-10 category	A_i	D_i	E_i
1	82.2	0.000045	7.0
5	79.4	0.00006	10.0
6	78.6	0.00006	10.0
7	81.4	0.00004	7.6
8	81.0	0.000075	8.4
9	81.6	0.000035	7.6
10	84.2	0.000005	5.2

To account for the effect of low noise tyres on total emission, the relative contributions of tyre and engine noise have to be considered. According to the road traffic noise model SonRoad [29] total emission of heavy vehicles at a speed of 80 km/h splits up into 40% engine noise and 60% tyre noise. Tab. 14 illustrates the relation between tyre noise modification and effect on total noise for each decibel increase or decrease attributing 60% to the effect of tyres.

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Tab. 14 *Effect of tyre noise modification ΔL_{tyre} in dB on total noise $\Delta L_{total,80km/h}$ at 80 km/h*

tyre noise modification ΔL_{tyre}	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
effect on total noise $\Delta L_{total,80km/h}$	-2.3	-1.9	-1.5	-1.1	-0.6	0.0	0.6	1.3	2.0	2.8	3.6

For -5 dB ≤ ΔL_{tyre} ≤ +5 dB this relation can be approximated with sufficient accuracy by

$$\Delta L_{total,80km/h} = 0.026 \cdot \Delta L_{tire}^{\ 2} + 0.6 \cdot \Delta L_{tire}$$

Consequently the three emission models from above can be expanded to include information about the tyre emission with respect to a standard tyre (according to the tyre label): ΔL_{tyre}

$$L_{\max,80km/h} = L_{\max,80km/h,ref} + 0.026 \cdot \Delta L_{tire}^{\ 2} + 0.6 \cdot \Delta L_{tire}$$

If the effect of modified tyre emission on total is calculated with the recently proposed European noise model CNOSSOS [31], the expression reads as

$$L_{\max,80km/h} = L_{\max,80km/h,ref} + 0.0272 \cdot \Delta L_{tire}{}^{2} + 0.53 \cdot \Delta L_{tire}$$

A comparison of the two formulas reveals that the two models (SonRoad and CNOSSOS) predict very similar effects of ΔL_{tyre} on total noise, e.g. for a -3 dB low noise tyre, they differ by 0.2 dB only.

9.2.2 Noise Model for an urban speed regime

According to SonRoad, the acoustical energy contained in a pass-by of a heavy vehicle at 50 km/h is 3.7 dB(A) lower compared to a pass-by at 80 km/h. At a speed of 50 km/h, emission splits up into 57% engine noise and 43% tyre noise. Tab. 15 illustrating the relation between tyre noise modification and effect on total noise for each decibel increase or decrease.

***Tab. 15** Effect of tyre noise modification ΔL_{tyre} in dB on total noise $\Delta L_{total,80km/h}$ at 50 km/h.*

tyre noise modification ΔL_{tyre}	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
effect on total noise $\Delta L_{total,50km/h}$	-1.5	-1.3	-1.1	-0.8	-0.4	0.0	0.5	1.0	1.6	2.2	2.9

For -5 dB ≤ ΔL_{tyre} ≤ +5 dB this relation can be approximated with sufficient accuracy by

$$\Delta L_{total,50km/h} = 0.027 \cdot \Delta L_{tire}{}^{2} + 0.44 \cdot \Delta L_{tire}$$

And finally total noise is found as

$$L_{\max,80km/h} = L_{\max,80km/h,ref} + 0.027 \cdot \Delta L_{tire}{}^{2} + 0.44 \cdot \Delta L_{tire}$$

9.3 Costs related to noise

The ARE report [11] identifies external costs related to noise as shown in Fig. 5 and duplicated here in ***Tab. 16***.

***Tab. 16** External costs for three vehicle categories, expressed as per vehicle-km and per tonne-km respectively.*

	delivery van	truck	articulated lorry
Rp. per vehicle-km	3.8	15	15
Rp. per tonne-km	13	2.9	1.4

As there is only a weak correlationship between noise emission and weight, it is obvious to rely on the costs per vehicle-km. Under the assumption that the costs calculations are based on the acoustical energy produced by the traffic it can be concluded that a vehicle with a noise emission differing by ΔL with respect to the average vehicle causes costs $C(\Delta L)$ as given by

$$C(\Delta L) = C_{ref} \cdot 10^{0.1 \cdot \Delta L}$$

where C_{ref} represents the costs from Tab. 16. This is the same equation presented in section 7.4 with $\Delta L = x - x_{mean}$.

Using the equation above and considering the data in Tab. 14 and Tab. 15 the cost of 1 dB(A) can be estimated as shown in the following example: A truck with low noise tyres that emits 3 dB(A) less noise compared to the average fleet, generates 1.5 dB(A) (***Tab. 14***) less total noise on highways and 1.1 dB(A) (Tab. 15) less total noise in an urban environment. With ΔL = -1.5 dB(A) and -1.1 dB(A) the costs per vehicle-km calculated from the above equation result in 10.6 Rp. and in 11.6 Rp., compared to 15 Rp. for an average truck. This implies that a vehicle with low noise tyres would incur external costs due to noise that are 70% of the costs of the average vehicles with no low noise tyres (10.6 in comparison to 15) and therefore a bonus of 30% is recommended.

10 Classification of HDVs According to their Environmental Footprint

In order to classify vehicles according to their environmental footprint it is of paramount importance to consider where these vehicles travel. For example a vehicle travelling in urban areas will typically have a higher environmental impact than one travelling in less inhabited areas such as long haul vehicles. Unfortunately this factor is not distinguished in the external costs report [11] although the data for such a distinction is available.

10.1 Pollutant Emissions

As discussed in detail in section 4, the Swiss heavy vehicle charge or LSVA encourages vehicles with low pollutant emissions. The external health cost calculations [11] as summarized in section 5 are based on PM10. No other regulated pollutants (NOx, CO, particle mass, particle number) are used in the calculations. Due to the fact that the latest engines on the market have certain massive technical improvements regarding NOx and particle emission levels, it is recommended to adjust the Bonus/ Malus categories in the current LSVA charge. For example Euro IV and Euro V have deNOx devices and EURO VI has deNOX as well as particle filter. These technical advances imply that the current cost calculations in Fig. 5, Fig. 6 and Fig. 7 that are primarily due to pollutants caused by heavy vehicles will no longer be relevant in the future. Therefore the following revision to the pollutant emissions categories is recommended:

Cat P1 (no exhaust gas treatment technology), Euro 0, I, II, III (Malus)

Cat P2 (mild NOx or particle treatment technology), Euro IV, V

Cat P3 (highly effective NOx and particle treatment technology), Euro VI (Bonus)

10.2 Noise

Noise emissions are not significantly dependent on tonnage within a vehicle class; therefore, considering noise/tonne and kilometer, it is optimal to use 40 t vehicles. Considering the external costs of heavy vehicles, Fig. 6 shows that regarding noise, trucks and semi-trucks have the same external costs per km (15 CH cents/km) with delivery vehicles at 3.8 CH cents/km. Research in the footprint projects [14] has shown that in every category there are vehicles that are noisy and others that are less noisy. As tyre noise is the dominant source at higher vehicle speeds and in light of the new low noise tyre label, it is recommended that the noise bonus be given to vehicles with all low noise tyres based on the owner’s declaration. The following noise categories are therefore recommended:

Cat N1: All vehicle tyres are low noise (Bonus)

Cat N2: Not all tyres are low noise

Under the assumption that

- low noise tyres generate 3 dB less noise emission
- the driving performance develops mainly on highways (highway speed regime)

Total noise emissions of Cat N1 vehicles can be expected to be 1.5 dB(A) lower than Cat N2 emissions (***Tab. 14*** and ***Tab. 15***). This implies that a vehicle with low noise tyres would incur external costs due to noise that are 70% of the costs of the average vehicles with no low noise tyres (10.6 CH cents in comparison to 15.0 CH cents). This corresponds to 70% of the costs of Cat N2 vehicles. Consequently, the noise charge for N1 vehicles could be defined as 70% of the N2 charge.

10.3 Infrastructure damage

Heavy vehicles bear a disproportionate burden in causing damage to the infrastructure. This aspect should be considered in any cost calculations. Currently the federal office for statistics is looking into this aspect. In light of the fact that the weigh-in-motion sensors which measure the vehicles axle loads in situ are capable of measuring close to 7-10% accuracy, it could be possible for the vehicles to be checked in situ and those that are over this value to receive a fine. Vehicle overload is not legal and can therefore never be part of an incentive system. Addressing any violation of the law is the responsibility of the police. Any change to the LSVA should consider the fact that smaller vehicles with less axles emit less noise as shown in the pass by noise of SWISS5 at 84.5 dBA in comparison to 87.6 dBA (Fig. 15) for the largest SWISS10 vehicle category (see section 8). But at the same time it should be noted that transporting the same tonnage on less axles cause more damage to the infrastructure and any charging scheme should not encourage vehicles with less axles. On the other hand transporting less tonnage is less economically as well as environmentally desirable. What is important is that the goods are transported by the most economically and environmentally desirable manner. To this end fully loaded vehicles with loads distribution on many axles complying with the allowable axle loads should be encouraged.

10.4 Summary on Classification

The results of the above recommendations are summarized in Fig. 25.

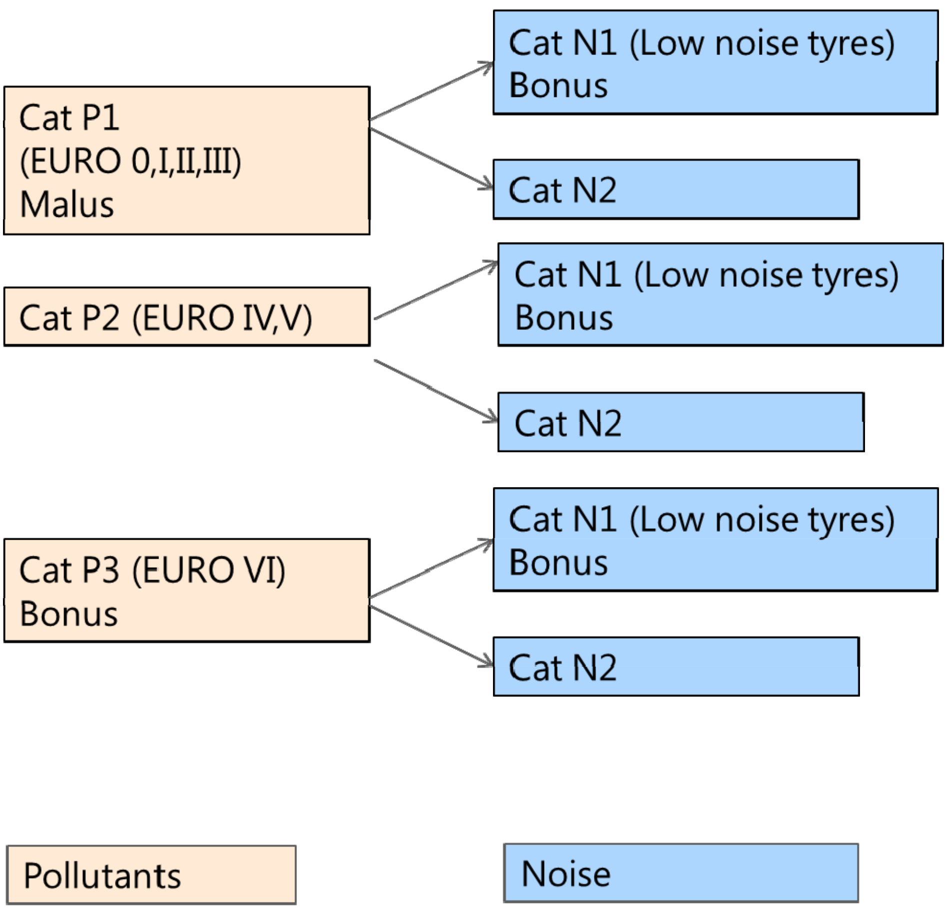


***Fig. 25** Recommended categories for pollutant emissions and noise*

Tab. 5 shows that in 2014 ca 66% of vehicles were EURO V and 6% EURO IV which would imply that they would pay the average charge, ca 18% would receive a bonus and the rest or 10 % would pay a malus. Furthermore, receiving a noise bonus would be based on self-declaration. The data for 2015 shows a similar trend with more EUROVI vehicles.

11 Options and Recommendations

The project results shown in the previous chapters indicate that a re-evaluation of the Swiss heavy vehicle charge (LSVA) is needed. This is on the one hand due to the change in the vehicle fleet and on the other hand due to the lack of incentives for low noise vehicles.

11.1 Options for an update of the Swiss Heavy vehicle charge (LSVA)

As discussed in section 5 the external costs of transport due to air pollution (health) and noise are as listed in ***Tab. 17***. These are two parameters that are used in the Ecovehicle project and therefore singled out here. As shown the external costs of freight trucks and articulated trucks with semi-trailers are similar per kilometre driven. However, when the tonnage is also considered the costs of semi's are lower since they can transport more tonnage.

Tab. 17 *External Costs of heavy vehicles due to air pollution and noise [11]*

External cost	Rp/km	Rp/tkm	Rp/km	Rp/tkm
	air pollution		noise	
Li (Delivery Trucks; Cat 5,6,7)	3.6	12.4	3.8	13
LW (Trucks, Cat 8, 9)	11.7	2.2	15	2.9
SS (Articulated Vehicles, Cat 10)	11.1	1.1	15	1.4

From ***Tab. 17*** it is possible to calculate the cost of one decibel additional noise as discussed in detail in section 9.3.

Tab. 18 *Calculation of the heavy vehicle charge (LSVA) based on external costs of transport and uncovered infrastructure costs [11]*

External costs of transport [CHF]	1.69E+09
Uncovered Infrastructure costs [CHF]	4.00E+08
Total costs [CHF]	2.09E+09
Swiss transport performance [t-km]	6.90E+10
LSVA rate [CHF/tkm]	0.0303
LSVA rate (total costs covered) [Rp/tkm]	3.03
Current rate [Rp/tkm]	2.69
Difference [Rp/tkm]	0.34

As discussed in section 4, the Swiss heavy vehicle charge is calculated using the external costs and the Swiss transport performance. Following this approach, the hypothetical LSVA was calculated using the latest external cost figures. In ***Tab. 18*** the external cost of transport and the additional uncovered cost of infrastructure are added (total costs) and then divided by the transport performance (Fig. 12) leading to a new value for the heavy vehicle charge for the average vehicle of 3.03 Rp/tkm that is 0.34 Rp/tkm more than the current rate of 2.69 Rp/tkm. Further discussion for differentiation and a bonus/malus regime is discussed in section 10. Using the current LSVA differentiation discussed in section 4, and considering the transport performance sample from the fourth quarter in 2014 (Tab. 5) , 1.8 % of vehicles would receive a malus (EURO0, EUROI, EUROII), 8.6% (EUROIII) pay the average charge and the rest or the majority receive a bonus. This current scenario would not encourage environmentally friendly vehicles in the future. Using the recommendation discussed in section 10 and considering the transport performance, 66% of vehicles (EURO V) would pay the average charge of 3.03 calculated in ***Tab. 18***, 18 % (EURO VI) would pay a bonus and 10% a malus.

Considering the total costs of heavy vehicles shown in ***Tab. 17***, the additional charge of 0.34 Rp/tkm can be justified when the external costs of noise shown in ***Tab. 17*** i.e 1.4, 2.9, and 13 Rp/tkm are taken into account.

Considering the transport performance and total costs, the following LSVA scenarios are conceivable where the uncovered infrastructure costs of heavy vehicles are included in scenarios 3 and 5 and distributed in accordance to transport performance of each Euro category:

Scenario 1 (Status Quo):

Remain with the change in LSVA effective Jan 1st 2017 by the federal department of transport (BAV) discussed in section 4. This option does not include a “Low Noise Bonus”.

In order to demonstrate the difference in revenue the traffic make-up of the 4th quarter in 2015 (Tab. 5) is used. In addition the charge for transporting 40 tonnes 300km is calculated. As shown below, under this hypothesis the revenues from LSVA would be $440x10^6$ CHF.

scenario 1-status quo 2017					
	4th Q 2015			price for	hypothetical
Euro class	**Tonne-kilometer**	**Percent**	**tarif Rp/tkm**	**300km-40t**	**revenue [CHF]**
Euro 0	55'015'372	0.3%	3.1	372	1'705'477
Euro 1	30'360'973	0.2%	3.1	372	941'190
Euro 2	146'033'532	0.9%	3.1	372	4'527'039
Euro 3	1'039'897'284	6.1%	3.1	372	32'236'816
Euro 4	715'462'638	4.2%	2.69	322.8	19'245'945
Euro 5	9'719'629'322	57.3%	2.69	322.8	261'458'029
Euro 6	5'264'230'561	31.0%	2.28	273.6	120'024'457
Total	**16'970'629'682**	**100%**			440'138'953

Scenario 2 (Current LSVA + Low Noise Bonus 30%):

- Keep categories as recommended by scenario 1 (Cat 2: EUROIV and V)
- Keep current LSVA rate of 2.69 Rp/tkm for Cat. 2
- Add a “Low Noise Bonus” of 30% for vehicles that declare they are using all low noise tyres. This bonus is recommended considering the minimum external cost of noise shown in ***Tab. 17***.

For the purpose of demonstration, using scenario 2 with the hypothesis that 10% of t-km in each category is transported by low noise tyres and receiving a 30% low noise discount the total revenue will be $427x10^6$ CHF.

scenario 2-assume 10% in each category have low noise tyres recieving 30% r					noise bonus		
	4th Q 2015			price for	w. 30% Bonus	price for	hypothetical
Euro class	**Tonne-kilometer**	**Percent**	**tarif 1 Rp/tkm**	**300km-40t**	**tarif 2 Rp/tkm**	**300km-40t**	**revenue [CHF]**
Euro 0	55'015'372	0.3%	3.1	372	2.17	260.4	1'654'312
Euro 1	30'360'973	0.2%	3.1	372	2.17	260.4	912'954
Euro 2	146'033'532	0.9%	3.1	372	2.17	260.4	4'391'228
Euro 3	1'039'897'284	6.1%	3.1	372	2.17	260.4	31'269'711
Euro 4	715'462'638	4.2%	2.69	322.8	1.883	225.96	18'668'567
Euro 5	9'719'629'322	57.3%	2.69	322.8	1.883	225.96	253'614'288
Euro 6	5'264'230'561	31.0%	2.28	273.6	1.596	191.52	116'423'723
Total	**16'970'629'682**	**100%**					426'934'784

Scenario 3 (New LSVA + Low Noise Bonus 30%):

- Use new rate of LSVA 3.03 Rp/tkm for Cat. 2 (EUROIV and V)
- Add a "Low Noise Bonus" of 30%.

For the purpose of demonstration, using scenario 3 with the hypothesis that 10% of t-km in each category is transported by low noise tyres and receiving a 30% low noise discount the total revenue will be $461x10^6$ CHF.

scenario 3-increase cat 2 to 3.03; assume 10% in each category have low noise					bonus		
	4th Q 2015			price for	w. 30% Bonus	price for	hypothetical
Euro class	**Tonne-kilometer**	**Percent**	**tarif 1 Rp/tkm**	**300km-40t**	**tarif 2 Rp/tkm**	**300km-40t**	**revenue [CHF]**
Euro 0	55'015'372	0.3%	3.1	372	2.17	260.4	1'654'312
Euro 1	30'360'973	0.2%	3.1	372	2.17	260.4	912'954
Euro 2	146'033'532	0.9%	3.1	372	2.17	260.4	4'391'228
Euro 3	1'039'897'284	6.1%	3.1	372	2.17	260.4	31'269'711
Euro 4	715'462'638	4.2%	3.03	363.6	2.121	254.52	21'028'162
Euro 5	9'719'629'322	57.3%	3.03	363.6	2.121	254.52	285'669'625
Euro 6	5'264'230'561	31.0%	2.28	273.6	1.596	191.52	116'423'723
Total	**16'970'629'682**	**100%**					461'349'717

Scenario 4 (Current LSVA +High Noise Bonus 50%):

- Retain LSVA rate of 2.69 Rp/tkm for Cat. 2 : EUROV and IV
- Add a large "Low Noise Bonus" of 50%.

For the purpose of demonstration, using scenario 4 with the hypothesis that 10% of t-km in each category is transported by low noise tyres and receiving a 50% low noise discount the total revenue will be $418x10^6$ CHF.

scenario 4- assume 10% in each category have low noise tyres recieving 50%					noise bonus		
	4th Q 2015			price for	w. 50% Bonus	price for	hypothetical
Euro class	**Tonne-kilometer**	**Percent**	**tarif 1 Rp/tkm**	**300km-40t**	**tarif 2 Rp/tkm**	**300km-40t**	**revenue [CHF]**
Euro 0	55'015'372	0.3%	3.1	372	1.55	186	1'620'203
Euro 1	30'360'973	0.2%	3.1	372	1.55	186	894'131
Euro 2	146'033'532	0.9%	3.1	372	1.55	186	4'300'688
Euro 3	1'039'897'284	6.1%	3.1	372	1.55	186	30'624'975
Euro 4	715'462'638	4.2%	2.69	322.8	1.345	161.4	18'283'648
Euro 5	9'719'629'322	57.3%	2.69	322.8	1.345	161.4	248'385'127
Euro 6	5'264'230'561	31.0%	2.28	273.6	1.14	136.8	114'023'234
Total	**16'970'629'682**	**100%**					418'132'005

Scenario 5 (New LSVA + Noise Bonus for number of axles):

- New rate of LSVA 3.03 Rp/tkm for Cat. 2 : EUROV and IV
- Add noise categories (Noise Bonus/Malus) based on number of axles
  Remark: noise is strongly correlated to number of axles (section 8.2.1) and this option is in line with the European harmonisation plans (presentation Bruno Hofstetter 2016). This option will not encourage low noise tyres nor will it reduce damage to infrastructure as less axles distribute the load less and cause more damage to infrastructure, therefore this scenario is not recommended.

  This option is comparable with the rail noise bonus in CH, D, NL. A calculation for this scenario is not possible as the number of axles is not known.

Discussion

Tyre bonus

When introducing a low noise tyre bonus it should be noted that this would have to be on the basis of self-declaration that could be proven and verified by presenting an invoice for example and verified in addition by spot checking respectively at the vehicle check points using the designation on the tyre. Aging of tyres and how this affects the noise emissions is not considered. This has to be checked after 200'000 km which is the life of tyres. 3 levels of tyre noises exist currently, the recommended two levels of noise bonus allows for future development. Another option to reduce noise would be to encourage the tyre industry to phase out non-low noise tyres by providing incentives to them.

Engine noise

In inner-city environments when the vehicle speed is below 50 km/h the engine noise is dominant however, low noise tyres will help reduce the noise (***Tab. 15***). Modern vehicles with improved casing of the engine should be encouraged.

Delivery trucks (Lieferwagen)

Any change to the LSVA should consider the fact that smaller vehicles with less axles emit less noise as shown in the pass by noise of SWISS5 at 84.5 dBA in comparison to 87.6 dBA (Fig. 15) for the largest SWISS10 vehicle category (see section 8). But at the same time it should be noted that transporting the same tonnage on less axles cause more damage to the infrastructure and any charging scheme should not encourage vehicles with less axles. On the other hand transporting less tonnage is less economically as well as environmentally desirable. What is important is that the goods are transported by the most economically and environmentally desirable manner. To this end fully loaded vehicles with loads distribution on many axles complying with the allowable axle loads should be encouraged.

Summary of findings

In this section various scenarios for a possible revision to the LSVA have been developed in order to introduce a noise bonus. Calculations have been made using traffic data from one quarter (4th quarter 2015) assuming that 10% of t-km transported in each category receives a noise bonus. The table below shows this would lead to a maximum of +/-5% deviation in revenue from the status quo as shown in the table below.

	Hypothetical revenue [CHF]	% change from scenario 1
scenario 1-status quo	440'138'953	0
scenario 2	426'934'784	-3
scenario 3	461'349'717	5
scenario 4	418'132'005	-5

11.2 Recommendations

1. Due to the introduction of deNox and particle filters a shift in EURO categories is recommended. Various scenarios have been developed and discussed below.
2. Effect of the bonus/malus system on the future development of the vehicle fleet should be considered.
3. Bonus for low noise tyres can be given on the basis of self-declaration
4. Any change to the LSVA should consider the fact that less axles results in less noise, at the same time transporting the same tonnage on less axles cause more damage to the infrastructure and any charging scheme should not encourage vehicles with less axles such as delivery trucks (Lieferwagen).
5. More research needs to be devoted to determining the accuracy of the tyre label. Recent studies show that in situ noise measurements do not corroborate tyre labels.

12 European Cooperation

Switzerland has coordinated the project that was managed by Sciotech projects UK. The project received Eureka label E!7219 in 2014 which is necessary to get funding in some member countries. The members of the project were Switzerland (Empa, Quantis, Kistler); Czech Republic (SVUM), United Kingdom (Transport for Scotland, Sciotech Projects, q-free).

As discussed in section 3, five tasks were defined for the Eureka project. Within task 1 the quality of data was analysed and methods developed for checking weigh-in-motion (WIM) data. These results are summarized in the paper in annex III. Task 2 has been inactive as the partners interested in this task (transport for Scotland) have dropped out of the project. Task 3 was the topic of workshop 5 which is summarized in annex II. Furthermore categories for vehicles were identified in section 10. Within task 4 costs were related to impact and this part is summarized in section 8. Within task 5 a web site was established to allow dissemination of the information within the project (empa.ch\ecovehicle). Several conference and journal publications were produced as summarized in section 14 and eight workshops were organised at Empa to address various aspects of the project. A summary of these workshops is provided in annex II.

The primary contribution of the Swiss team was to tasks 3, 4 and 5 although data was delivered for task 1 (shown in annex II). As such the data from a Swiss monitoring site was used to produce a total footprint of individual vehicles, and relate these footprints to the external costs and based on the data and the future development of vehicles recommendations for revision to the LSVA were made (section 11).

An important part of the European cooperation in this project was the eight workshops organised at Empa bringing together all stakeholders on the road and rail side. The workshops were attended by 15 to 20 specialists leading to a multi-disciplinary exchange of ideas. The program and a summary of the workshops are included in annex II and are summarized below.

Workshop 1: Cost effective solutions for noise reduction of road and rail transport

Noise generation is one of the most important factors limiting the EU's transport. This has been the subject of the EU's noise directive (2002/49/EC) and also the EU's greening transport package (MEMO/08/492 08/07/2008) in which the idea of a bonus/malus incentive was described. As noise arises from the interaction of a wheel/tyre with its infrastructure, this workshop reviewed cost effective solutions for both road and rail modes and the role of regulation and incentives.

Workshop 2: Options for reducing gaseous emissions associated with road and rail transport

Gaseous emissions, alongside noise, are one of the factors limiting transport world-wide, particularly in urban areas. The second workshop considered the options for reducing gaseous emissions associated with road and rail transport.

Workshop 3: Options for reducing damage to infrastructure from road and rail vehicles

The vehicle and infrastructure form a coupled system which result in an energy transfer between them in the form of dynamic as well as static forces which each has to withstand. In this workshop technology to reduce this interaction as well as to monitor it, and incentives such as user access charging was discussed.

Workshop 4: Options for reducing carbon dioxide emissions from road and rail vehicles

In this workshop, the options for the reduction in carbon dioxide emissions from both road and rail transport were reviewed against a background of rising energy prices, increased societal concern about pollution, EU regulation and legislation and industrial initiatives.

Workshop 5: Classifying environmentally friendly road and rail vehicles

In the 5th workshop each of the major impacts were considered in order to develop a classification scheme based on in situ measurements of these impacts where possible. The goal was to design an "EU type label", which can form the basis of a dialog between vehicle manufacturers, vehicle operators and infrastructure maintainers.

Workshop 6: Road and rail vehicles: Impacts, Costs, Incentives

The speakers at this Workshop explored the principle that the polluter should pay for the impact they create on the infrastructure and the environment: that is the polluter should pay both the external as well as the internal cost. Switzerland is the only European country where the principle has been agreed and is being applied. In this Workshop, impacts were related to cost for both road and rail vehicles followed by a discussion of what type and level of incentives should be considered to encourage manufacturers to offer and operators to buy vehicles that were environmentally friendly.

Workshop 7: Data for classifying environmentally friendly road and rail vehicles

With the ever increasing environmental impact of road and rail traffic, it becomes increasingly important for vehicles to become more environmentally friendly. The topic considered in this 7th Ecovehicle workshop related to the type and quality of data which would enable road or rail vehicles to be classified.

Workshop 8: Labelling environmentally friendly vehicles

In a series of workshops with stakeholders, the major environmental impacts have been identified and reviewed. These are –

- fuel consumption
- carbon dioxide emissions
- damage to the pavement or track
- audible noise

and it is proposed to capture this vehicle information in an EU-type label. By bringing these impacts together it will enable the buyer to purchase a vehicle which meets his needs and is also environmentally friendly. It could also provide a basis for applying road usage or track access charges and for internalising some of the external costs currently carried by society. The vehicle label developed is shown in Fig. 26.

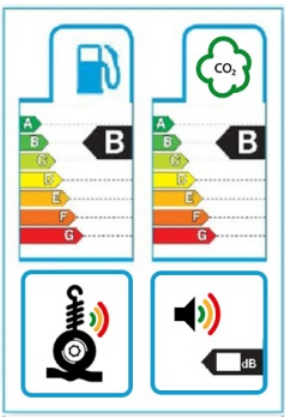


Fig. 26 *Vehicle label developed within the Eureka Project*

13 Summary and Conclusions

The project Eureka Ecovehicle was a European cooperative project with the overall aim to identify the environmental footprint of road and rail vehicles and encourage those with a low footprint. Switzerland has been a member of the predecessor project Eureka Footprint E!2486 since 2004 and has coordinated the current project. The project received Eureka label E!7219 in 2014 which was necessary to get funding in some countries and was managed by Sciotech projects, UK. The members were Switzerland (Empa, Quantis, Kistler); Czech Republic (SVUM), United Kingdom (Transport for Scotland, Sciotech Projects, q-free).

Five tasks were identified within the project those were: Task 1: refining measurement techniques Task 2: methods of informing operators; Task 3: developing an environmental index for road and rail vehicles; Task 4: relating impact to costs and Task 5: dissemination. The Swiss partners have been primarily active in task 3, 4 and 5. Within task 1 the quality of data was analysed and methods developed for checking weigh in motion (WIM) data. These results that include data from Switzerland from the St. Prex WIM monitoring site are summarized in the paper in annex III. Task 2 has been inactive as the partners interested in this task (transport for Scotland) became inactive in the course of the project. Task 3 was the topic of workshop 5 which is summarized in annex II. Within task 4 costs were related to impact and this part is summarized below. Within task 5 a web site was established to allow dissemination of the information within the project (www.empa.ch\ecovehicle). Several conference and journal publications were produced as summarized in chapter 14 and eight workshops were organised at Empa involving Swiss and international stakeholders also from outside the project to address various aspects of the project as summarized in annex II.

The latest report on external costs of transport in Switzerland published by ARE [11] shows that the road freight traffic cost 7.1 Rp/tkm of which 4.4 Rp/tkm was internalised through the heavy vehicle charge (LSVA), implying in turn that 2.7 Rp/tkm was not covered by the charge. The external cost of rail on the other hand were 2.8 Rp/tkm, air freight 7.6 Rp/tkm whereas ship on the Rheine was 0.5 Rp/tkm.

The Swiss heavy vehicle charge or LSVA encourages vehicles with low pollutant emissions. The development of the traffic fleet has shown that the newer vehicles are primarily EURO V (66% in 2014) and therefore most are environmentally friendly in terms of pollutant emissions. In order to further encourage this trend, the following revision to the pollutant emissions categories is recommended:

Cat P1 (no exhaust gas treatment technology), Euro 0,I, II, III (Malus)

Cat P2 (mild NOx or particle treatment technology), Euro IV, V

Cat P3 (highly effective NOx and particle treatment technology), Euro VI (Bonus)

Research by the authors has shown that the vehicles with newer engines are not necessarily less noisy rather in every category there are vehicles that are more noisy and those that are less. This implies that there is a margin for improving the noise emissions of vehicles. According to the road traffic noise model SonRoad [29] total emission of heavy vehicles at a speed of 80 km/h splits up into 40% engine noise and 60% tyre noise. At highway speeds of above 50 km/h that is relevant for the data set used here, the acoustical emission is dominated by tyre noise whereas the engine noise component plays only a minor role. Whereas in urban environments where the speed is below 50 km/h, the engine noise is dominant. It was shown in highway speeds that using low noise tyres can contribute significantly to reducing the overall noise of heavy vehicles. In order to encourage vehicles to use low noise tyres it is recommended to establish a 30% bonus to the LSVA when all tyres are low noise. The low noise tyre verification would have to be based on self-declaration.

The latest external cost of transport (data from 2010, published in 2014) and the additional uncovered cost of infrastructure are divided by the transport performance in 2014 leading to the heavy vehicle charge of the average vehicle of 3.03 Rp/tkm that is 0.34 Rp/tkm more than the current rate of 2.69 Rp/tkm. Using this scheme and considering the transport performance for 2014 more than 66% of vehicles (EURO V) would pay the average charge of 3.03, 18 % (EURO VI) would receive a bonus and 16% a malus. It should be noted that the reported external costs are not aggregated into the different vehicle categories as only three categories are defined. More research needs to be devoted into the allocation of costs to the various vehicle categories.

Considering the external costs of heavy vehicles, the additional charge of 0.34 Rp/tkm can be justified when the external costs of noise are taken into account.

When introducing a low noise tyre bonus it should be noted that this would have to be on the basis of self-declaration that could be proven and verified by presenting an invoice for example and verified in addition by spot checking respectively at the vehicle check points using the designation on the tyre. Aging of tyres and how this affects the noise emissions is not considered. This has to be checked after 200’000km which is the life of tyres. 3 levels of tyre noises exist currently, the recommended two levels of noise bonus allow for future development. Another option to reduce noise would be to encourage the tyre industry to phase out non-low noise tyres by providing incentives to them. The latest feedback from the scientific community indicates that more research needs to be devoted to determining the accuracy of the tyre label. Recent limited studies show that in situ noise measurements do not always corroborate tyre labels.The EU tyre label provides a means to evaluate tyres from the point of view of noise and to encourage low noise tyres. The tyre noise data from a large vendor indicates that the variance in the tyres regarding noise emissions (>3 dBA) shows that there is a great potential to lower traffic noise by using low noise tyres

Various scenarios for a possible revision to the LSVA have been developed in order to introduce a noise bonus. Calculations have been made using traffic data from one quarter (4^{th} quarter 2015) assuming that 10% of t-km transported in each category receives a noise bonus. The calculated data shows this would lead to a maximum of +/-5% deviation in revenue from the status quo revenues (effective 01.01.2017).

Any change to the LSVA should consider the fact that the various parameters considered in this report are influencing the infrastructure and the environment differently for example less axles results in less noise, at the same time transporting the same tonnage on less axles causes more damage to the infrastructure and any charging scheme should not encourage vehicles with less axles such as delivery trucks (Lieferwagen).

14 Publications

In addition to presentations made at the eight workshops organised as part of this project, the results were and are being disseminated through the following publications and presentations at international conferences and peer reviewed journals:

1. Poulikakos, L.D., Mayer, R.M., Heutschi, K., Soltic, P., Lees, A., Van Loo, H.: Defining road and rail vehicles with a low environmental footprint. Transport Research Arena, TRA 2016, Warsaw.

2. Poulikakos, L D, Heutschi, K, Soltic, S., Del Duce, Andrea. Relating impact of heavy vehicles to the external costs. International Conference on Weigh in Motion, ICWIM7 2016, Foz de Iguazu Brazil.

3. Heutschi, K., Bühlmann, E., Oertli, J., Options for reducing noise from road and rail vehicles. Transportation Research Part A: Policy and Practice, vol. 94, 308-322 (2016).

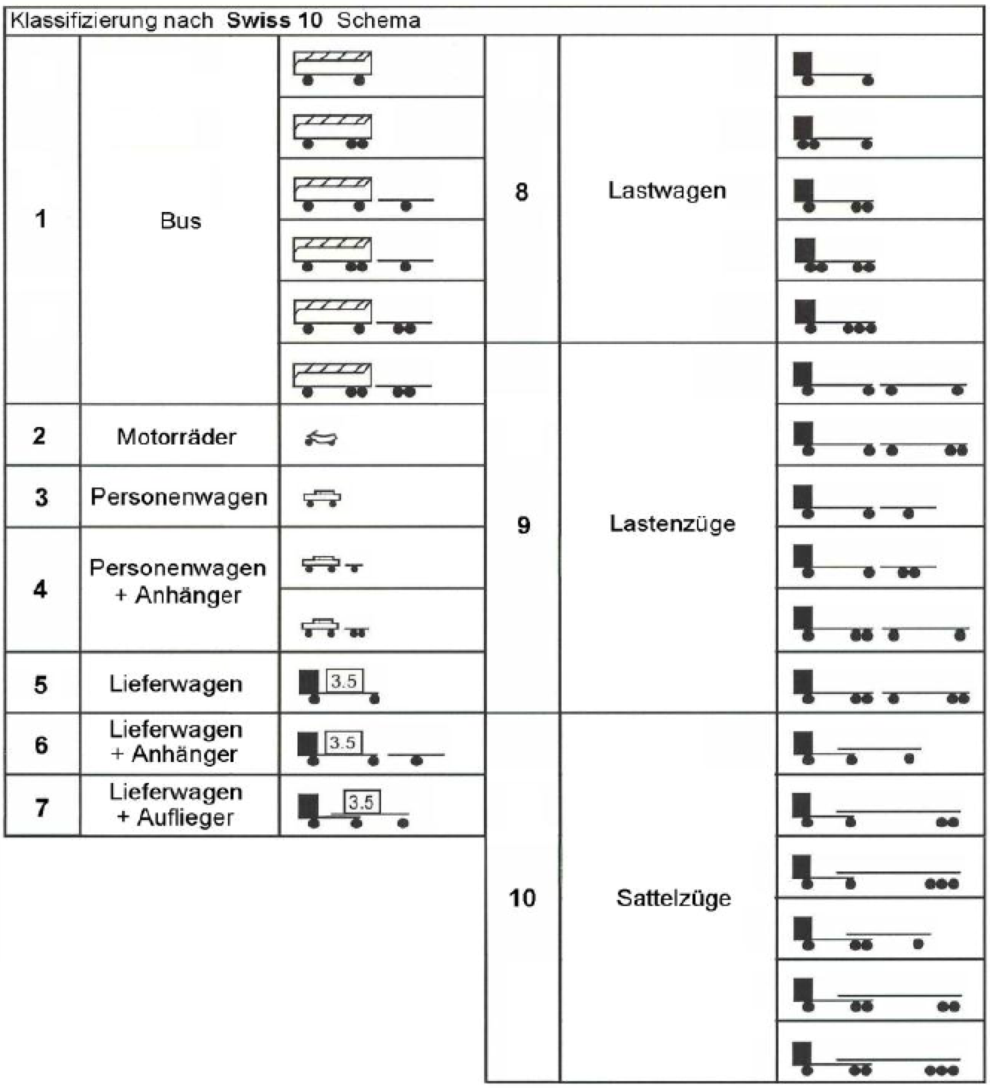
4. Poulikakos, L.D., Heutschi K., Soltic, P., Del Duce, A. Relating the environmental impact of heavy duty vehicles to the external costs and Eco-Points induced through road transport, submitted

15 Acknowledgements

The authors would like to convey their appreciation to the Eureka project partners for their cooperation and especially to Dr. Rayner Mayer for his leadership throughout all aspects of the project. Furthermore the contribution and support of the accompanying commission (Begleitkommission) is gratefully acknowledged.

Annexes

I SWISS 10 Vehicle Categories


Klassifizierung nach **Swiss 10** Schema

1	Bus
2	Motorräder
3	Personenwagen
4	Personenwagen + Anhänger
5	Lieferwagen
6	Lieferwagen + Anhänger
7	Lieferwagen + Auflieger
8	Lastwagen
9	Lastenzüge
10	Sattelzüge

II Ecovehicle Workshops

II.1 Workshop 1: Cost effective solutions for noise reduction of road and rail transport

The 1st Ecovehicle workshop took place on Tuesday 17 June, 2014 11.30 to 16:15 at Empa Dübendorf. The program is shown the figure below.

BACKGROUND

Noise generation is one of the most important factors limiting the EU's transport . This has been the subject of the EU's noise directive (2002/49/EC) and also the EU's greening transport package (MEMO/08/492 08/07/2008) in which the idea of a bonus/malus incentive was described. As noise arises from the interaction of a wheel/tyre with its infrastructure, this workshop will review cost effective solutions for both road and rail modes and the role of regulation and incentives.

Ecovehicle is a Eureka project whose aim is to define and encourage the uptake of road and rail vehicles with a low environmental footprint. As part of its work programme, the project is organising a series of workshops relating to various criteria for such vehicles.

Switzerland has become the first country in Europe to introduce environmental taxes/bonuses on road and rail transport. For road vehicles, much of the revenue has been used to finance the two deep level rail tunnels under the Alps in order to introduce a modal shift of freight from road to rail.

To initiate the transformation to low noise rail vehicles, a bonus system has been introduced for vehicles equipped with low noise (composite) brake blocks. In addition a further bonus has been introduced for braking on discs rather than on the wheel tread.

Now that Euro 6 engines are available with very low environmental emission levels, the Federal Government is considering introducing a bonus/malus system for quiet road vehicles.

This workshop is therefore very timely in reviewing cost effective solutions for low noise road and rail vehicles.

Documentation: http://www.eureka.be; http://www.mobilityplatform.ch

PROGRAM

11.30	Lunch, EMPA canteen
12.30	Reducing the environmental impact of road and rail vehicles – introduction Lily Poulikakos, Empa
12.50	EU energy label and Tyre design Rayner Mayer, Sciotech Projects
13.10	Pavement design – opportunities and costs Erik Bühlmann, GROLIMUND+PARTNER AG
13.30	Discussion
13.50	Noise control possibilities in railways Jakob, Oertli, SBB
14.10	Low noise braking systems Speaker to be announced
14.30	Discussion
14.50	Tea and coffee
15.10	External cost of noise Ueli Balmer, Swiss Federal Office for Spatial Development (ARE)
15.40	Panel discussion
16.20	Conclusions
16.30	End of workshop

II.1.1 Summary of workshop 1

Background

Ecovehicle is a Eureka project whose aim is to define and encourage the uptake of road and rail vehicles with a low environmental footprint. As part of its work programme, the project is organising a series of workshops relating to various criteria for such vehicles.

Noise generation is one of the most important factors limiting the EU's transport. This has been the subject of the EU's noise directive (2002/49/EC) and also the EU's greening transport package (MEMO/08/492 08/07/2008) in which the idea of a bonus/malus incentive was described. As noise arises from the interaction of a wheel/tyre with its infrastructure, this workshop reviewed cost effective solutions for both road and rail modes and the role of regulation and incentives.

Presentations

Road

Lily Poulikakos reviewed the data collected during the Eureka project Footprint, the predecessor to the Ecovehicle project. This showed that a small number of vehicles (7%) in almost all vehicle categories were overloaded or noisy. Whether this was known to the vehicle operators was unknown.

Rayner Mayer described the origins of the EU labelling scheme and its application to tyres. This type of label not only initiated a dialogue between buyer and seller, but would also enable maximum noise limits to be enforced for tyres (72 dB in 2016). Erik Buhlmann discussed the introduction of low noise pavements in both southern and northern Switzerland. Noise reduction had been effective but their durability was still unknown.

Rail

Jakob Oertli reviewed EU noise policies and incentives and the initiatives that had been introduced by the Member /States. Since noise was an environmental concern, the Commission was consulting over a new policy initiative and this was scheduled for publication this autumn.

Rayner Mayer enumerated the available options for low noise freight bogies and concluded that new designs could make freight bogies as quiet as passenger bogies.

External cost of noise

Ueli Balmer described the work that ARE was doing on determining he external cost of noise related to human health and nuisance value. This study would be published on 30 June. If a vehicle classification could be established for noise then the composition of the Swiss Heavy Goods Vehicle could be adjusted to include a cost element for noise.

Panel discussion

Three questions were discussed –

Incentives versus regulation – do we need both?

After some discussion, it was agreed that incentive followed subsequently by regulation might be an optimal solution; also that incentives could be provided by environmental taxes provided that this did not disadvantage any one mode.

In-situ measurements the most effective way of enforcement

The consensus was that self-declaration followed by spot checks involving pre-selection was the most effective method.

Should transit countries cooperate to minimise noise reduction?

The conclusion was that this was highly desirable in order to prevent transit traffic moving routes to countries with low environmental taxes. It would also accelerate introduction of low noise technology. Regional cooperation was already established for certain freight corridors such as Rotterdam to Genoa.

II.2 Workshop 2: Options for reducing gaseous emissions associated with road and rail transport

The 2nd Ecovehicle workshop took place on Tuesday October 14, 2014 11.30 to 16:15 at Empa Dübendorf. The program is shown the figure below.

SYNOPSIS

There is an ever increasing need for stabilising the world's carbon emissions by 2020 and then to decrease these by a minimum of 3 % each and every year up to at least 2100 (5th IPCC assessment report). In addition in many cities and along traffic corridors, WHO guidelines are exceeded for pollutants like PM10, SO_X and NO_X. Transport, like any other sector, will therefore have to become more efficient and reduce both its local and global emissions.

The reduction in gaseous emissions will be reviewed against a background of rising energy prices, increased societal concern about pollution, EU regulation and legislation and industrial initiatives and what options exist for further reductions in emissions. The advent of Euro VI heavy duty diesel engines will significantly reduce gaseous and particle emissions in the transport sector whilst car manufacturers are facing, in addition to the strict limits for pollutants, CO_2 fleet average limits of 130 g/km in 2015 and 95 g/km in 2021. For vehicles with electric propulsion, there will have to be increased emphasis on decarbonising the electricity supply as some 70 % of the EU's electricity is produced from fossil fuels which have a high carbon content.

In this second workshop organised by the Eureka project, Ecovehicle, the options for reducing gaseous emissions associated with vehicle propulsion will be explored in the context of limiting local and global environmental impacts.

Following presentations by invited speakers the workshop will conclude with a panel discussion to which attendees will be able to contribute on how to define and encourage road and rail vehicles with a low environmental footprint.

TARGET AUDIENCE

The workshop will be of interest to transport engineers, town and city planners, authorities striving to improve local and global environments.

PROGRAM

11.30	Lunch, Empa canteen
12.30	Reducing the gaseous emissions associated with road and rail transport – Introduction Patrik Soltic, Empa
12.50	Trends in vehicle emissions Harald Jenk, Swiss Federal Office for the Environment, FOEN
13.10	Achievements with Euro VI and beyond Peter Krähenbühl, FPT Powertrain Technologies
13.30	Discussion
13.50	Strategies for managing gaseous emissions in Scotland Transport Scotland
14.10	Progress in decarbonising the electricity supply Rayner Mayer, Sciotech projects
14.30	Discussion
14.50	Tea and coffee
15.10	External cost of pollution Ueli Balmer, Swiss Federal Office for Spatial Development (ARE)
15.40	Panel discussion
16.20	Conclusions
16.30	End of workshop

II.2.1 Summary of workshop 2

Background

Ecovehicle is a Eureka project whose aim is to define and encourage the uptake of road and rail vehicles with a low environmental footprint. As part of its work programme, the project is organising a series of workshops relating to various criteria for such vehicles.

Gaseous emissions, alongside noise, are one of the factors limiting transport world-wide, particularly in urban areas. The dilemma is that those who live adjacent to such transport corridors do not benefit from such traffic flows and there is conclusive evidence that their health is affected.

The World Health Organisation has set limits on concentrations of the principal emissions associated with internal combustion engines such as SOx, NOx and hydrocarbon particulates. However in many cities these limits are exceeded during the summer months.

In addition there are two further constraints – emissions of *greenhouse* gases principally carbon dioxide, and *resource* constraints, which include the peak in conventional oil supplies and the approaching peak in conventional gas supplies.

So a business as usual approach cannot help in managing the transition to a more sustainable use of transport.

The second workshop considered the options for reducing gaseous emissions associated with road and rail transport.

Diesel engine technology

In burning petrol or diesel unwanted by-products included

CO – toxic

Unburnt HC – some of which are carcinogenic or toxic

Nitrous oxides – toxic precursor for ozone formation

Particles – some of which are volatile, toxic or carcinogenic

So diesel engine technology has evolved in a series of steps from euro I to euro VI which involved additional treatment of the unwanted by-productrs including

Diesel oxidation catalysts

Particle filter

Selective catalytic reduction

Exhaust gas recirculation in some engines

On-board diagnostics were used to ensure that these treatments were effective.

Trends in vehicle emissions

Harold Jenk described trends in vehicle emissions and how exhaust standards had successfully reduced both NOx and PMs by a factor of almost 10. The data showed that for heavy goods vehicles, real world and laboratory measured emissions were similar except when the engine was cold i.e. when starting up. This was a concern in urban areas with traffic flow where stop/start driving conditions were encountered. There had been no reduction however in CO_2 emissions.

For passenger cars, exhaust standards had lowered NOx and PMs and also EU regulations had succeeded in reducing CO_2 emissions. So for Switzerland, the outcome was a strong decline in NOx and HC and CO_2 had peaked and would slowly decline.

Beyond euro VI

Peter Krahenbuhl (Fiat Power Trains) described additional technologies which were being investigated which would increase the overall fuel efficiency of the power plant from 45% to a target value of 55%, which might be achieved by 2020.

This should be possible using integrated energy management including on-board energy storage to reduce fuel consumption in stop/start city traffic.

Low emission strategy

Stephen Thomson (Transport Scotland) described the steps being undertaken to introduce low emission zones in Scotland. This was necessary because some areas were in breach of obligations to maintain air quality. He believed that the primary concern should be linked to health rather than energy or climate change.

His Department was required to produce a low emission strategy which would be adopted by June 2015 following consultations with the 32 local authorities.

Decarbonising the electricity grid

Rayner Mayer (Sciotech Projects) reviews progress in decarbonising the electricity grid. The increase in renewables has been very significant driven by a tenfold reduction in the cost of solar PV. By 2020 it was predicted that investment in renewable sources would overtake that of fossil fuels whose share of new generation would continue to decline. The key to balancing the grid demand would be the ability to switch loads of which heat pumps for heating (and cooling) dwellings and recharging batteries of electric vehicles would become the principal switchable loads.

An example of a new type of frequency switch was illustrated which would be trialled on Fair Isle, an isolated community between Shetland and Orkney, who derived their electricity from wind power.

Swiss heavy goods vehicle fee

Ueli Balmer (BAFU) described the origin of this fee and how the external costs (and benefits) had been derived. Health, noise and climate change accounted for 70% of this cost. For cycling, the external cost exceeded the external benefit while for walking the reverse applied.

The reduction of 10% in HGV fee for euro VI equipped trucks had been dramatic and the percentage of vehicles equipped with such engines now exceeded 90% of the transit traffic.

Panel discussion

The role of regulation and incentives was considered in some detail and it was concluded that both were required. Regarding driver education, the panel was less convinced how successful this might be. It was suggested that the transition from leaded to lead free petrol in the 1980’s be reviewed.

General

Lily Poulikakos made a small presentation to Ueli Balmer to thank him for his contributions to Empa over many years. She wished him a happy and active retyrement and hoped he would continue to participate in such workshops.

Rayner Mayer

Reading

II.3 Workshop 3: Options for reducing damage to infrastructure from road and rail vehicles

The 3rd Ecovehicle workshop took place on Wednesday February 18th from 11.30 to 16:15 at Empa Dübendorf. The program is shown the figure below.

SYNOPSIS

Road and rail infrastructure comprise an important asset of any country and a vital contributor to its economy and society. However the interaction between a vehicle and its infrastructure be it road or rail is very non-linear and can increase up to the 4th power of the axle load for road vehicles. For rail vehicles operating on poorly aligned track, unloading on one wheel can lead to overloading of up to 60% on the other wheels so adding a further degree of dynamic loading.

In the light of ever increasing volumes of transit traffic, it is therefore important to reduce damage to the infrastructure and that of the infrastructure to the vehicle by minimising the static and dynamic interaction between these two components. It is also necessary to identify and advise the operators of the small proportion of vehicles which are overloaded and that can cause significant damage to the infrastructure and to their vehicle.

With improved technical standards it is a timely topic to discuss options to reduce this disproportionate damage to the infrastructure considering new technology and policy options.

Many countries have policy in place to limit such damage through track access or road usage charging.

As part of their work programme, this third workshop is being organised by the Eureka project, Ecovehicle. The various options will be introduced by a group of speakers and this will be followed by a panel discussion to which attendees will be encouraged to contribute their viewpoint.

TARGET AUDIENCE

The workshop will be of interest to transport engineers, town and city planners, authorities striving to improve local and global environments.

REGISTRATION

There is no charge for attendance but please register your interest in attending and contributing to the discussion.

PROGRAM

11.30	Lunch, Empa canteen
12.30	Overview, Ecovehicle project Lily Poulikakos, Empa
12.40	Effect of long and heavy vehicles on damage to the pavement Parisa Khavassefat, KTH
13.00	Effect of vehicle suspension on pavement and track Rayner Mayer, Sciotech Projects and Ivo Cerny, Svum
13.20	Reacting track forces Stefan Koller, SBB track unit
13.40	Discussion
14.00	State of the art in weigh in motion for road and rail Hans van Loo, Kistler
14.20	Status of direct enforcement using weigh in motion sensors Bernard Jacob
14.40	Discussion
14.55	Tea and coffee
15.10	Differentiated track access charging Jochen Holzfeind, SBB
15.25	Panel discussion
16.05	Conclusions
16.15	End of workshop

II.3.1 Summary of workshop 3

Options for damage to infrastructure from road and rail vehicles

Notes of 3rd workshop, EMPA 18 February 2015

The vehicle and infrastructure form a coupled system which resulted in an energy transfer between them in the form of dynamic as well as static forces which each has to withstand. Some 20 people from five countries participated in the workshop.

Lily Poulikakos (Empa**)** provided an overview of the Ecovehicle project whose goal was to develop the concept of an environmentally friendly vehicle as a means of reducing the environmental impact of transport. This involved both measuring the impact and relating to external cost.

Parisa Rossel-Khavassefat (KTH) considered the dynamic impact of long and heavy vehicles to the pavement. This required the use of finite element analysis to understand both the elastic and viscoelastic behaviour of the asphalt layer. The longer the vehicle, the higher was the increase in the dynamic stress at the bottom of the asphalt layer. So any increase in length would have to be compensated by better design.

As Bernard Jacob pointed out in his talk, only minor changes were being negotiated for the revision of EC directive 96/53 on weights and dimensions of heavy vehicles.

Rayner Mayer (Sciotech Projects) considered the principal parameters which influenced suspension design – these included vehicle speed, infrastructure alignment, sprung and unsprung mass. He illustrated how the material properties of steel, rubber and glass reinforced plastic (GRP) had influenced suspension design and concluded that the potential of GRP had yet to be realised.

Sensors

Hans van Loo (Kistler) described the use of sensors in detecting forces exerted by road and rail vehicles on the infrastructure. With suitable design of the sensor arrays, it was possible to undertake tolling according to weight and to detect vehicles which exceeded legal limits. Such systems had a high reliability, good accuracy and high durability.

Enforcement

Stefan Koller (SBB) described the sensor array that had been installed across the Swiss rail network. This enabled them to monitor mass, axle load, wheel force and unbalanced side loads. There were three levels – safe, warning and intervention and operators were notified in real time if these levels were exceeded. This intervention had enhanced safety and reduced delay times and maintenance. In addition operators had been able to maintain good wheel condition before defects had got too large. The proportion of overloaded vehicles was about 5% - 10% and *was decreasing*.

Bernard Jacob (IFFSTTAR) described the enforcement that the Czech Republic had introduced since 2011 on their highways. Operators had not only to pay a toll but also for vehicles carrying excessive weight, to reduce or redistribute their load. This had resulted in less damage to their pavement. A similar scheme was being evolved in France with the introduction scheduled for 2017 once the reliability and reproducibility of the measuring systems had been verified.

Track access charge

Jochen Holzfeind (SBB) described a new initiative supported by SBB and BfV for a differentiated track access charge which was related to the ‘wear factor’ of the track by passing vehicles. This was deemed essential to reducing track maintenance thus increasing capacity and enabling a further modal shift from road to rail.

Panel discussion

Q1: Is the condition of the vehicle and its suspension more important than that of the infrastructure?

This was agreed and that enforcement was an essential element in reducing the impact of overloaded or damaging vehicles.

Q2: What factor would be most beneficial in reducing the dynamic interaction?

Consensus was axle load which varied as 4^{th} power for road and 3^{rd} power for rail.

Q3: Should the polluter pay?

In Switzerland it was expected that the polluter should pay the full external cost. Within the EU the 2008 ‘Green transport package’ allowed member states to charge the full external costs provided this was applied to all modes.

Rayner Mayer

Reading

19/02/2015

II.4 Workshop 4: Options for reducing carbon dioxide emissions from road and rail vehicles

The 4th Ecovehicle workshop took place on Thursday June 25th from 11.30 to 16:30 at Empa Dübendorf. The program is shown the figure below.

SYNOPSIS

The goal of Ecovehicle is to promote the concept of road and rail vehicles with a low environmental footprint and, more specifically, to define a classification for those vehicles, which can be considered environmentally friendly.

In this Eureka project workshop, the options for such the reduction in carbon dioxide emissions from both road and rail transport will be reviewed against a background of rising energy prices, increased societal concern about pollution, and carbon emissions. As a major pollutant source, transport will have to make its contribution towards reducing carbon emissions.

Carbon dioxide is the principal by-product of the combustion of fossil fuels like oil and gas and is thus the principal gas responsible for global warming. All available evidence suggests that human activity is inducing changes in the climate at a rate, at which ecosystems cannot adapt. In order to limit irreversible changes in climate, the IPCC concluded that it will be necessary to stabilize the world’s carbon emissions by 2020 and then to decrease these by a minimum of 3% each and every year up to at least 2100 if the average temperature rise is not to exceed two degrees Centigrade (5th IPCC assessment report).

The workshop topics have been selected to illustrate the wide range of options for reducing such emissions, most of which impact on other technologies. Transforming the market for such carbon reducing technologies involves an analysis of costs, benefits and environmental impact such as electric vehicles and encouraging a modal shift from road to rail. So for electricity to be the energy source for electric vehicles and the modal shift from road to rail, the electricity supply will have to be decarbonised, which will require increasing amounts of renewable energy sources as well as storage. The speakers will be followed by a panel discussion to which all participants will be encouraged to contribute their viewpoint.

TARGET AUDIENCE

The workshop will be of interest to scientists and engineers, planners, local, regional and federal authorities striving to improve local and global environments.

PROGRAM

11.30	Lunch, Empa canteen
12.20	View electricity to gas demonstrator Christian Bach, Empa
12.45	Overview Ecovehicle project Lily Poulikakos, Empa
13.00	Reducing transport emissions through innovation and entrepreneurship Katherine Foster, Climate KIC
13.20	Options for reducing mass and increasing payload of rail vehicles Rayner Mayer, Sciotech Projects
13.40	Inducing modal shift from road to rail Jens-Erik Galdiks, SBB
14.00	Discussion
14.20	Conversion of electricity to gas as a means of energy storage Christian Bach, Empa
14.40	Potential of electric vehicles to reduce emissions from road transport Gil George, ETHZ
15.00	Discussion
15.15	Tea/coffee break
15.35	Cost and benefits of investing in sustainable use of energy now Viola John, ETHZ
15.55	Panel discussion
16.30	Conclusions and end of meeting

II.4.1 Summary of workshop 4

Synopsis

Carbon dioxide is the principal by-product of the combustion of fossil fuels like oil and gas and is also the principal gas responsible for global warming. All the available evidence suggests that human activity is inducing changes in the climate at a rate at which ecospecies cannot adapt. In order to limit irreversible changes in climate, it will be necessary to stabilise the world's carbon emissions by 2020 and then to decrease these by a minimum of 3% each and every year up to at least 2100 (5th IPCC assessment report).

So transport which is a major pollutant source and very dependent upon on the availability of fossil fuels, will have to contribute its fair share of reductions in carbon emissions.

In this workshop, the options for the reduction in carbon dioxide emissions from both road and rail transport were reviewed against a background of rising energy prices, increased societal concern about pollution, EU regulation and legislation and industrial initiatives.

Ecovehicle overview

Lily Poulikakos (Empa) gave an overview of the Ecovehicle project whose primary goal was to reduce the environmental impact of road and rail transport. One reason why the use of transport was increasing was because, with the exception of the Swiss Heavy Goods Vehicle fee, users were *not* paying the external cost associated with the environmental and social impacts of transport. The biggest differences in cost between road and rail were –

the incidence of accidents which were far fewer with rail than road

the use of electric rather than diesel propulsion in trains which minimised CO2 emissions

Another reason for the increase in transport was that the formation of the single market had led to much more mobility of people and goods.

Innovation for low-carbon prosperity

Katherine Foster described the creation of Climate KIC, one of the three original **K**nowledge and **I**nnovation **C**ommunities whose mission was to bring innovative products to market relating to climate mitigation and adaptation. More than 200 projects had received funding relating to the principal topics of low carbon cities, zero carbon production systems and adaptive water management.

Options for decreasing mass and increasing payload of rail vehicles

Rayner Mayer described the options which included the use of lighter and stronger materials and innovative design through the functional integration of components. Using available technology, it should be possible to save in excess of one million tonnes of carbon dioxide across the European freight wagon fleet of 500,000 wagons. Unlike aircraft, there was a lack of innovation in rail freight wagon design and incentives needed to be offered by infrastructure maintainers to drive the innovation.

Conversion of electricity to gas

Christian Bach described the options for converting excess renewable electricity into synthetic fuels like hydrogen and methane. This is technically feasible and is a relatively cheap option for a significant reduction in CO_2 emissions of vehicles. While powertrains of passenger cars are hard to change, it would be much easier for other types of vehicles such as buses, delivery and municipal vehicles. This type of vehicle could complement that of electric propulsion.

A visit was made to the future mobility demonstrator facility at Empa, which had just been completed.

Potential of electric vehicles to reduce emissions from road transport

Gil George emphasised that mobility was the greatest source of CO_2 emissions in Switzerland, of which passenger cars emitted more than half. Electricity had 100% mitigation potential if it was produced from decarbonised sources such as renewable energy or fossil fuel sources with carbon capture and storage. This application would have significant impact on the electricity grid if large scale electric mobility was introduced and this was being studied and modelled by a group at ETHZ.

Costs and benefits of investing in sustainable use of energy now

Viola John described the increasing demand for energy particularly from the 'transition' and developing countries. The marginal cost of production was much lower for renewable energies than fossil fuels so, once the renewable energy facility was built, there was very little on-going cost. The use of feed in tariffs most notably if Germany had resulted in a very big increase in renewable generated electricity, which had resulted in lower production costs and reduced atmospheric emissions.

Conclusions

There were numerous options for reducing CO_2 emissions from road and rail transport. Incentives were required to get new technologies accepted as the users were currently only paying the marginal part of the external cost. There was a need to accelerate the transition to low CO_2 vehicles if the average global temperature rise was to be limited to 2°C.

II.5 Workshop 5: Classifying environmentally friendly road and rail vehicles

The 5th Ecovehicle workshop took place on Thursday November 19th 2015 from 9.30 to 16:30 at Empa Dübendorf. The program is shown the figure below.

SYNOPSIS

The environmental impact of transport within Europe is increasing due to the increased mobility of people and goods. Products for example can be designed in one country, manufactured in another and sold in all European countries while people can live and work in any Member State of the European Union.

To reduce this environmental impact the Ecovehicle project is developing a concept of road and rail vehicles with a low environmental footprint and is aiming to define a classification for vehicles in order to promote those that are environmentally friendly.

In previous Ecovehicle workshops (www.empa.ch/ecovehicle), the four major environmental impacts have been reviewed which are

- noise
- environmental pollution
- damage to pavement and track
- emissions of carbon dioxide

In this 5th workshop each of these major impacts will be considered in order to develop a classification scheme based on in situ measurements of these impacts where possible.

The idea is then to capture this information in a new design of "EU type label", which can form the basis of a dialog between vehicle manufacturers, vehicle operators and infrastructure maintainers.

The workshop will end with a panel discussion on how to develop the classification scheme and label.

TARGET AUDIENCE

The workshop will be of interest to scientists and engineers, planners, local, regional and federal authorities striving to improve local and global environments.

PROGRAM

9:30	**Introduction to the project** Lily Poulikakos, Empa
9:50	**Labelling criteria for environmentally friendly vehicles** Rayner Mayer, Sciotech Projects
10:10	**Classifying criteria for noise emissions** Kurt Heutschi, Empa
10:30	**Discussion**
10:45	**Coffee break**
11:05	**Classifying criteria for environmentally friendly suspension** Rayner Mayer, Sciotech Projects Ivo Cerny, SVUM Jan Chvojan, VZU
11:35	**Classifying criteria for energy efficient passenger vehicles and for carbon dioxide emissions** Swiss federal office for energy, BfE
11:55	**Discussion**
12:15	**Lunch**
13:15	**Contribution** Swiss federal office for spatial development, ARE
13:35	**View of stakeholders to labelling environmental friendly vehicles** to be introduced by Dominique Schneuwly, Swiss federal office for the environment, Bafu
14:15	**Discussion**
14:40	**Recommendations**
15:00	**End of workshop**

II.5.1 Summary of workshop 5

Welcome (Lily Poulikakos, Empa)

LP welcomed everyone to the 5th Ecovehicle workshop and hoped that there would be a good and interesting discussion. The goal of the Ecovehicle project was to reduce the environmental impact of road and rail transport. The project partnership was open-ended and other enterprises were welcome to join. The theme of this 5th workshop was related to the task of developing a label for environmentally friendly vehicles.

Purpose of labelling (Rayner Mayer, Sciotech Projects)

RM described how labelling of energy consuming products had evolved since the labelling framework directive had been introduced in 1992. The primary purposes of a label were to facilitate a dialogue between buyer and seller and for the buyer to be able to purchase a product that was closest to his needs. The label was also being used by manufacturers to market their products. The proposed label for environmentally friendly vehicles was based on the EU tyre label (Figure 1) which had encouraged tyre manufacturers to bring forward very low noise tyres.

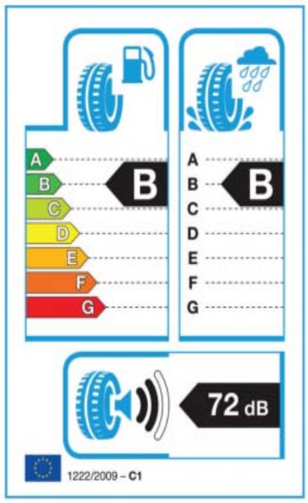
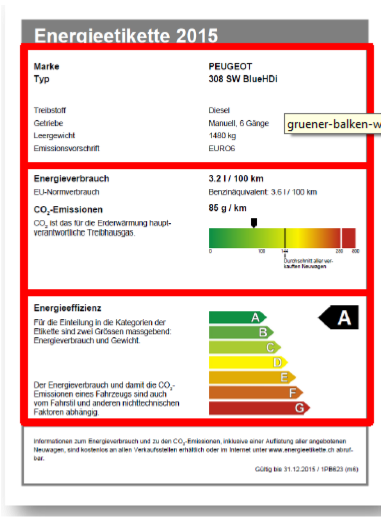


Figure 1: EU tyre label

Swiss car label (Christoph Schreyer, BfE)



CS described the Swiss car label which had to be displayed on all new car sales but was optional for 2nd hand cars. As it was a dynamic label, its classification was recalculated each year and could be downloaded from the BfE website. The goal was to reduce both energy consumption and greenhouse gas emissions of cars by raising awareness and to enable the consumer to make an informed choice. In addition the energy efficiency was divided into seven classes (A to G) with similar number of models in each classification (Figure 2). The car label was used by various cantons to determine the annual 'circulation' tax. What had been less successful was a life cycle analysis label which was regarded as too complex and provided no 'added' value.

Figure 2: Swiss car label

EU tyre label (Dominque Schneuwly, Bafu)

DS described how the EU tyre label had been promoted since its introduction in November 2012. It had influenced both consumer choice and the manufacturers' products. Consequently ultra-low noise tyres were now available which also had very good skid resistance. These new products did not seem to carry a price premium. If all cars in CH were fitted with such low noise tyres, the number of people affected by noise emissions could be reduced by up to 40% (Figure 3).

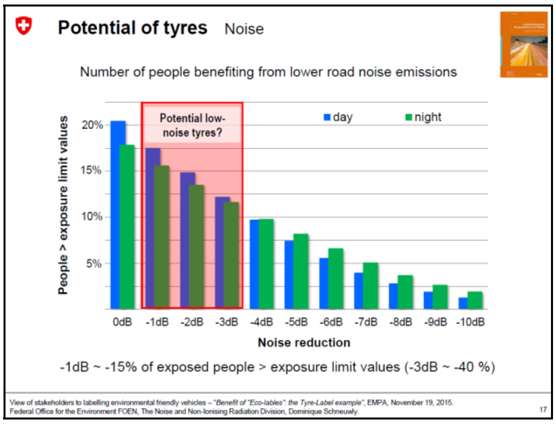


Figure 3: Potential for low noise tyres to reduce noise disturbance to persons living adjacent to major roads

Environmentally friendly suspensions (Rayner Mayer, Sciotech Projects)

RM described the characteristics of suspensions which were deemed road friendly. However the EU directives were not performance related so some road friendly suspensions were excluded. Both the UK and CH were promoting the benefits of track friendly suspensions but no EU agreement had yet been sought or agreed. So unlike road friendly suspensions there was little encouragement for track friendly bogies to be developed or marketed across Europe. However all available evidence suggested that suspensions that were road or track friendly also had low noise emissions. Hence such suspensions could be regarded as environmentally friendly.

Noise emissions (Kurt Heutschi, Empa)

KH described measurements that showed that at low speeds inside towns noise from engines of road vehicle dominated while out of town and at higher speeds, tyre noise dominated (Figure 4). He believed that no further significant noise reduction was likely after 2016 unless additional incentives were offered.

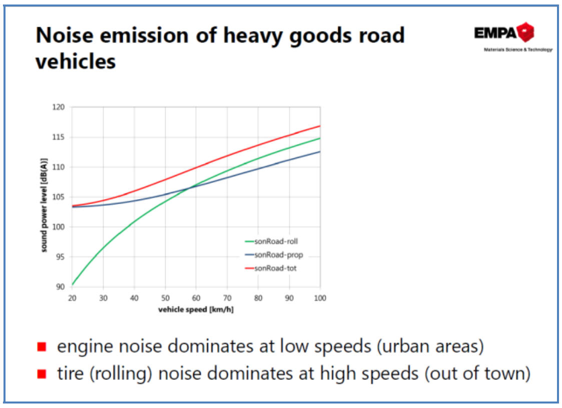


Figure 4: Noise emissions of heavy goods vehicles

For rail vehicles KH had developed a model which showed for very smooth tracks that disc brakes could significantly reduce sound power over composite brake blocks by preserving the roundness of the wheel (Figure 5). Such brakes were not in common use because of increased cost and increased mass. Freight operator AAE had the largest number of disc-braked wagons in service and that they were economic if these vehicles travelled long distances each year.

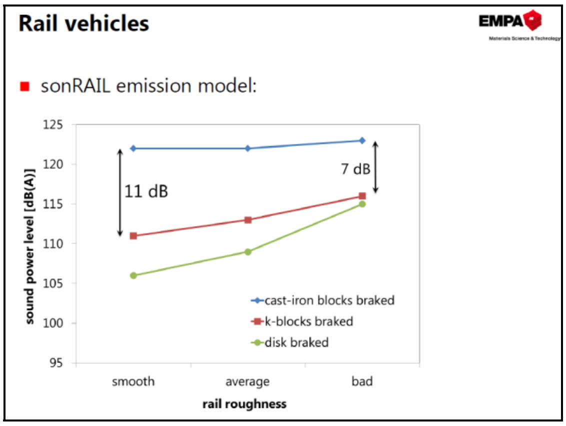


Figure 5: Predict sound power levels as a function of rail roughness

Labelling environmentally friendly vehicles

The concept of an environmentally friendly road or rail vehicle was reviewed and it was agreed that it should help to promote purchase of such vehicles. A label would then help to differentiate between more and less friendly vehicles (Figure 6). The proposed design was based on that of the EU tyre label following its successful introduction three years ago.

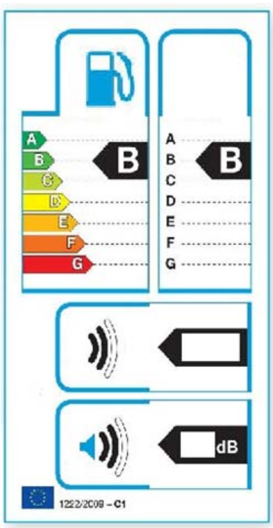


Figure 6: Outline of a proposal for a new EU label

Dominique Schneuwly (Bafu) described how such a label could be evolved (Figures 7-9).

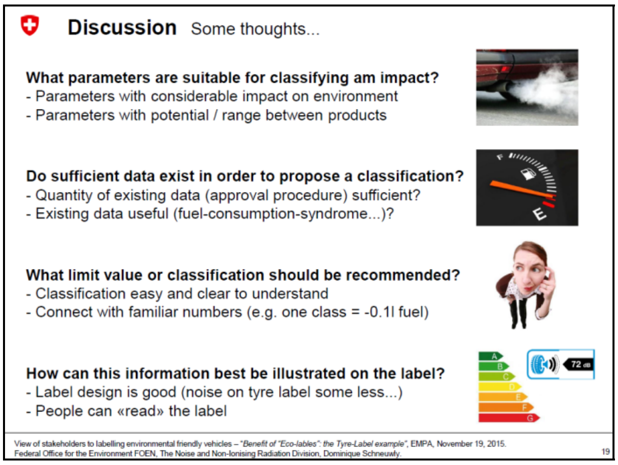


Figure 7: Which impacts and how to illustrate on label

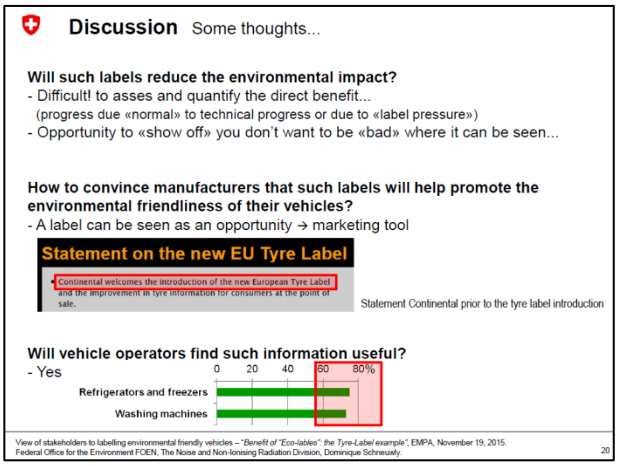


Figure 8: Possible impact of new label

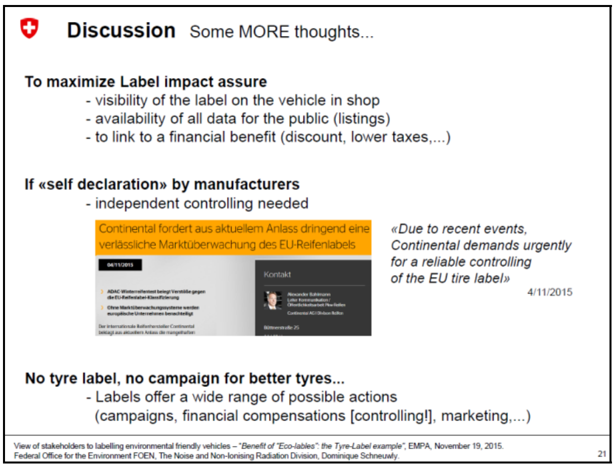


Figure 9: Maximising impact and checking manufacturers' self declaration

What impacts should be on the label (all)

For the label to have impact, it was agreed that the number of impacts should be limited to three or four and that these impacts should be measurable. Such impacts should be –

Noise – measured by pass-by method at a speed specified by norms

CO2 – suitable driving cycle(s) to be agreed

NOx – noted that emissions were higher for diesel than petrol engines

Environmentally friendly suspensions – relevant for freight vehicles; needs further discussion

Noted that different limit values were required for different classes of vehicles and modes (road or rail)

For some vehicles with a choice of fuel, the fuel type might need to be specified.

Encouraging uptake of environmentally friendly vehicles

This would form the topic of the next Ecovehicle workshop to be held 17 March 2016 at Empa. This would review relating impacts to costs and what incentives should be considered to promote their uptake

II.6 Workshop 6: Road and rail vehicles: Impacts, Costs, Incentives

The 6th Ecovehicle workshop took place on March 17, 2016; 9:30-15:00, at Empa Dübendorf. The program is shown the figure below.

SYNOPSIS

The environmental impact of transport within Europe is increasing due to the increased mobility of people and goods. Products for example can be designed in one country, manufactured in another and sold in all European countries while people can live and work in any Member State of the European Union.

To reduce this environmental impact the Ecovehicle project is developing the concept of road and rail vehicles with a low environmental footprint and aiming to define a classification for vehicles in order to promote those that are environmentally friendly.

Environmentally friendly vehicles can be defined as having a low impact with both its infrastructure and the environment. This will reduce the need for maintenance for both vehicle operator and infrastructure maintainer while society will benefit from lower environmental emissions.

In the first four Ecovehicle workshops, the four major environmental impacts have been reviewed which are

- noise
- environmental pollution
- damage to pavement and track
- emissions of carbon dioxide

The labelling of such vehicles was considered in the 5th workshop. The environmental impacts proposed are noise, NOx and carbon dioxide emissions and whether the vehicle suspension is road or track friendly.

In this 6th workshop, the role of incentives will be considered by relating impacts to costs for each of the major environmental impacts listed above.

The incentives to be reviewed will include:

- Rewarding operators of environmentally friendly vehicles by reduced usage charge or bonus payments
- Access to environmentally sensitive areas at night and during the day when air quality is poor.
- Imposing additional charges on vehicles with a high environmental impact or prohibiting (banning their usage)
- How labelling environmentally friendly vehicles will help buyers to identify these incentives.

Contributions are sought to this workshop as well as comments from stakeholders.

PROGRAM

9:30	**Introduction** Rayner Mayer, Sciotech Projects
9:50	**Relating impacts to external costs Road/Rail** Lily Poulikakos, Empa
10:10	**Incentives via charging through Swiss heavy good vehicle fee** Bruno Hofstetter, EZV
10:30	**Discussion**
10:45	**Coffee**
11:05	**Incentives for reducing noise emissions from rail** Robert Attinger, BAV
11:35	**Incentives for track friendly vehicles** Rayner Mayer, Sciotech Projects
11:55	**Discussion**
12:15	**Lunch**
13:15	**Incentives for using low noise tyres for road vehicles** Kurt Heutschi, Empa
13:35	**Relating measured impacts to external costs: Mass, Noise, Emissions** Lily Poulikakos, Kurt Heutschi, Patrik Soltic, Empa, Andrea del Duce, Quantis
14:15	**Comments by stakeholders**
14:45	**Discussion**
15:00	**End of workshop**

II.6.1 Summary of workshop 6

The speakers at this Workshop explored the principle that the polluter should pay for the impact they create on the infrastructure and the environment: that is the polluter should pay both the external as well as the internal cost. Switzerland is the only European country where the principle has been agreed and is being applied.

In this Workshop, impacts would be related to cost for both road and rail vehicles followed by a discussion of what type and level of incentives should be considered to encourage manufacturers to offer and operators to buy vehicles that were environmentally friendly.

External costs

Lily Poulikakos discussed the Swiss Spatial analysis of external costs for road and rail vehicles (www.are.admin.ch). The latest report based on 2010 costs indicated an amount of €573M of external costs were not internalised of which health and noise pollution created the highest burden. This cost could be equated to 2.7 rp (€cents)/tonne km.

With the introduction of the Euro 5 and Euro 6 diesel engines, gaseous pollutants per vehicle would decrease so leaving noise emissions as the only significant cost not covered by the current fee.

Incentives via charging of the Swiss heavy goods vehicle fee

Bruno Hofstetter (Swiss Customs Office) described the Swiss heavy goods vehicle fee which multiplied distance driven on all public roads x permitted total weight x tariff class which depended upon the Euro emission class of the engine. The outcome was that –

- Transport operations considered route optimisation and maximising load factors
- Fleet investment which could be recovered from bonus payments

The data showed that this fee had influenced operator's choice of engine and had accelerated the trend towards new vehicles and new engines with much lower level of pollutants. Now under discussion was a harmonised EU tolling service with classification based on vehicle registration documents. So if bonus/malus payment was to be introduced for tyres then this information would need to be added to the vehicles documents.

Track access charges

Robert Attinger (BAV) outlined the revisions to the Swiss track access charge from 2017 onwards. These included –

- Pollution malus
- Noise bonus
- Wear (or damage) factor
- Energy consumption

All of which formed part of the criteria for environmentally friendly rail vehicles as proposed by the Ecovehicle project and displayed on the proposed label.

What was evident from the noise bonus that this would not be sufficient by itself to induce the change to quieter vehicles so Switzerland was proposing to bar entry to 'noisy' rail vehicles from 2020 onwards. Like with harmonisation of road usage charging, a single entry point scheme would be introduced in Switzerland, Germany and Netherlands for granting noise bonus.

Rayner Mayer (Sciotech Projects) outlined three examples where the track access charges could be used to induce the uptake of environmentally friendly technology which would be mutually beneficial for the operator, infrastructure maintainer and society. These were –

- Braking on axle mounted discs rather than the wheel tread which would increase braking performance, bearing and wheel life and decrease forces going into the track
- Steering around curves – either passive (Ecobogie) or active (Tatravagonka) – will reduce contact between wheel flange and rail head thus reducing noise, wheel and rail head wear and lateral forces and increase bearing life
- Load equalisation on twisted track which could reduce dynamic track loading by 25%

Of these improvements, Switzerland had introduced a bonus payment for disc mounted brakes whilst the UK and Switzerland included a wear factor inside their track access charge.

Noise bonus for low noise tyres

Kurt Heutschi (Empa) discussed the potential of low noise tyres to reduce environmental impacts. Based on the ARE data, a bonus of up to 4 Rp (€cent) per tonne km could be justified. As the additional cost of low noise tyres was ca 30 CHF/tyre, this would result in an additional capital outlay of 300 CHF against a possible bonus of 8,000 CHF over tyre lifetime of 200,000 km. The reduction in average noise levels of heavy goods vehicles would be 1.5 dB.

Revision to Swiss heavy goods vehicle fee

Lily Poulikakos described two options for revising the heavy goods vehicle fee. Both involved a bonus payment for vehicles fitted with low noise tyres which could be recovered by charging a higher overall fee as impacts were increasing.

Conclusions

Usage charges could help to transform the market for environmentally friendly vehicles by providing incentives to persons who operated such vehicles. The proposed environmentally friendly vehicle label would encourage manufacturers to design such vehicles and infrastructure maintainers to harmonise such changes.

The next workshop scheduled for 22 June would review the type and quality of data that could be used to classify such vehicles.

II.7 Workshop 7: Data for classifying environmentally friendly road and rail vehicles

The 7th Ecovehicle workshop took place on 22nd June 2016; 9:30-15:00, at Empa Dübendorf. The program is shown below.

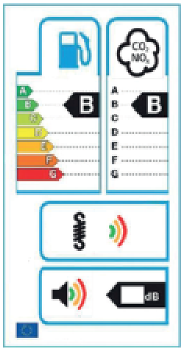
SYNOPSIS

The environmental impact of transport within Europe is increasing due to the increased mobility of people and goods. Products for example can be designed in one country, manufactured in another and sold in all European countries while people can live and work in any Member State of the European Union.

To reduce this environmental impact the Ecovehicle project is developing the concept of road and rail vehicles with a low environmental footprint and aiming to define a classification for vehicles in order to promote those that are environmentally friendly.

In the previous Ecovehicle workshops, the four major environmental impacts have been reviewed which are

- Noise
- Environmental pollution
- Damage to pavement and track
- Emissions of carbon dioxide



The idea is to capture this information in a new 'EU-type label' which can form the basis for a dialog between vehicle manufacturers, vehicle operators and infrastructure maintainers.

The goal of this 7th workshop is to review what data are available to characterize these impacts and whether the data are of a quality which can be used to classify road or rail vehicles. This is of particular significance following admissions by some vehicle manufacturers that some of their data are not eligible. The workshop will concentrate on options for reducing noise because it is the impact that is most directly associated with increasing levels of traffic. It is also the impact for which technological advances will enable emissions level to be reduced. The workshop will also consider the introduction of green corridors to reduce the environmental impact of freight traffic.

PROGRAM

9:30	Introduction to project Lily Poulikakos, Empa
9:50	Labelling criteria for environmentally friendly vehicles Rayner Mayer, Sciotech Projects
10:10	Low noise emissions from tyres Michelin
10:30	The development of low rolling resistance truck tyres: the outcome of the LORRY project Luc Goubert, Belgian Road Research Laboratory
10:50	Coffee
11:10	Discussion
11:30	Potential for reducing noise emissions from rail vehicles SBB Cargo
11:50	Discussion
12:15	Lunch
13:30	A noise label for motor vehicles: towards quieter traffic Johan Sliggers, Ministry of Infrastructure and Environment, NL
13:50	Sweden – Italy freight transport and logistics Green Corridor Jerker Sjogren, Jespo Konsult
14:10	Reducing environmental impact of transit traffic through Alpine corridors BAFU or ARE
14:30	Discussion
14:50	Recommendations
15:10	End of workshop

II.7.1 Summary of workshop 7

Introduction

With the ever increasing environmental impact of road and rail traffic, it becomes increasingly important for vehicles to become more environmentally friendly. The topic considered in this 7th Ecovehicle workshop relates to the type and quality of data which would enable road or rail vehicles to be classified.

Noise

It is clear from various surveys that noise of passing traffic is the most noticeable environmental impact, particularly along traffic corridors and Alpine/Rhine valleys. While noise barriers can shield some of those affected by noise pollution, it is clearly not possible to shield everyone impacted by noise emissions. The EU target of a 30% shift of freight from road to rail will only be feasible if existing freight wagons are substantially quieter to avoid creating an even larger environmental impact.

While technology is available to reduce noise emissions from railway wagons, there is little incentive for this to be used. The TIS demonstration train has set a target of reducing emissions by 10 dB using current technology while the Ecobogie hopes to achieve this by substituting fibre composites for steel in the bogie frame.

Two contributions considered the options for reducing noise from rubber tyres. The possibilities included altering and stiffening the groove geometry ad altering the composition of the carbon black used in manufacture. However noise reductions are only possible if the other performance requirements such as skid resistance on wet roads can be maintained (or improved).

The EU tyre label had encouraged manufacturers to produce low noise tyres with increased skid resistance. A further reduction of 2 – 3 dB seemed technically possible.

CO2 emissions

All the available evidence including detailed measurements along the Swiss Alpine motorways A2 an A13, indicated that in spite of vehicles becoming more energy efficient, CO2 emissions had not decreased. This trend suggested that road transport was unlikely to contribute any further CO2 reduction per se.

A holistic approach was therefore needed. Amongst EU initiatives, the shift to rail could contribute to a reduction in CO2 emissions. This could be quantified with the opening of the new base level Gotthard rail tunnel as the journey time by rail would be significantly reduced.

Another initiative was the formulation of nine Green Transport Corridors of which the longest was from Finland to Sicily. The development of such corridors was to facilitate movement of goods and peoples with low environmental impact by a combination of transport modes. A study coordinated by Jesjo Konsult had made a set of recommendations to the member states located along the Finland/Sicily corridor.

Other emissions

Monitoring of the Trans Alpine routes in Switzerland showed that NOx, NO2 and HC particulates had decreased and that this trend was likely to continue as the heavy goods vehicle fleet switched from euro 5 to euro 6 engines.

Making best use of available technology

For both road and rail, technology was available to reduce environmental impact. The consensus was that this would require information to be available to buyers at time of purchase. In addition, some form of financial incentive was required to promote the market transformation process.

Adjusting the Swiss heavy goods vehicle fee to encourage the uptake of more environmentally friendly vehicles was one of the outputs of the Ecovehicle project and recommendations had been made to the relevant Federal Ministries.

For the rail mode, the way to encourage the uptake of environmentally friendly vehicles was to differentiate the track access charge or to offer subsidies for example to low noise vehicles. Switzerland had decided unilaterally to ban all noisy rail vehicles from 2020 and Germany was considering doing likewise. What was needed was more data relating to vehicle/track interaction to enable infrastructure maintainers to decide how to further vary their charges to encourage the uptake of such technology.

Vehicle label

A further option for reducing environmental impact was to develop a label which would classify the environmental impact and fuel efficiency of any road or rail vehicle. The advantages of such a label included –

- promoting dialogue between buyer and seller
- enabling manufacturers to differentiate their vehicles and promote environmental friendliness
- providing a basis for internalising some or all of the external costs
- enabling manufacturers to bring forward new technology

Data availability and quality

For the road mode, there was much data which had been measured according to relevant norms and standards. Whilst data quality could always be improved and also the measurement methods, there was at very least sufficient data in order to classify vehicles. The fact that some data were not representative of vehicles in service use was a separate issue which industry had to resolve.

On the other hand, for the rail mode there was a lack of data which can only be resolved by industry initiatives like the TIS demonstration train and measurements of vehicle/track interaction on representative track.

Conclusions and recommendations

The environmental impact of road and rail vehicles had to be reduced as well as their socio/economic costs in order for land transport to reduce its environmental impact including climate change.

Data were available for all impacts which could enable a label for heavy duty road vehicles to be trialled. The existing measuring network for noise and emissions across the Alpine passes could be used to monitor any reduction in these impacts.

For rail vehicles, there is a lack of systematic and reliable data to cover all its environmental impacts. However the TIS demonstration train will provide an opportunity to acquire data which demonstrates all current technologies. Such data should include the interaction of the vehicle on the track and its substructure.

For the concept of an environmentally friendly vehicle label for road and rail vehicles to be adopted, it is recommended that a new programme of work should be drafted which should be considered at the 8th and final workshop to be held on 8 December at Empa.

II.8 Workshop 8: Labelling environmentally friendly vehicles

The 8th Ecovehicle workshop took place on December 8th 2016; 9:30-16:45, at Empa Dübendorf. The program is shown below.

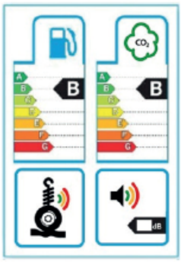
SYNOPSIS

The environmental impact of transport within Europe is increasing due to increased mobility of people and goods. Products for example can be designed in one country, manufactured in another and sold in all European countries while people can live and work in any Member State of the EU. To reduce this environmental impact, the Ecovehicle project is developing the concept of road and rail vehicles with a low environmental footprint and aiming to define a classification for vehicles in order to promote those that are environmentally friendly.

In a series of workshops with stakeholders, the major environmental impacts have been identified and reviewed. These are

- fuel consumption
- carbon dioxide emissions
- damage to the pavement or track
- audible noise

It is proposed to capture this vehicle information in an EU-type label building on the ideas that were developed for the EU tyre label which has resulted in manufacturers developing and making available low noise tyres.



Draft environmental vehicle label with categories for fuel consumption, CO_2 emissions, infrastructure friendly suspensions and noise emissions.

By combining all the major impacts on a label, it will enable manufacturers to promote the concept of environmentally friendly vehicles. It could also provide a basis for applying road usage or track access charges and for internalising some of the external costs currently carried by society.

In this 8th and final workshop of this phase of the project, partners will discuss each of the various impacts and suggest how these could be classified on a label. Stakeholders such as vehicle manufacturers, component suppliers and representatives from Brussels and the relevant Swiss Federal Authorities have been invited to comment on this initiative and how this concept could be taken forward and trialled.

PROGRAM

9:30	**Overview of the Ecovehicle project** Rayner Mayer, Sciotech Projects
9:40	**IMPACTS** **Noise** (Kurt Heutschi, Empa) **CO_2 emissions/Fuel consumption** (Patrik Soltic, Empa) **Damage to infrastructure** (Lily Poulikakos, Empa) **Influence of suspension** (Ivo Cerny, SVUM) **Discussion**
10:50	**Coffee break**
11:10	**COSTS** **Combining the impact to costs** (Lily Poulikakos, Empa) **Environmental cost of rail freight transport** (SBB) **Discussion**
12:15	**Lunch**
13:15	**REGULATION AND LABELLING** **Introduction to role of EU regulation/** **Influence of labelling** (Dominique Schneuwly, BAFU) **EU tyre label** (Jean-Dominique Perrot, Michelin) **Environmentally friendly vehicle label** (Rayner Mayer, Sciotech Projects) **Discussion**
14:45	**Coffee break**
15:05	**DEVELOPING AN ENVIRONMENTALLY FRIENDLY VEHICLE LABEL** **Research perspective** (Luc Goubert, BRRC) **National perspective** (SBB) **EU perspective** (Jerker Sjögren, Jesjo Konsult) **Discussion**
16:00	**PANEL DISCUSSION** **Could labelling reduce environmental impacts?** (Ulf Sandberg, VTI)
16:30	**Conclusions**
16:45	**End of workshop**

II.8.1 Summary of workshop 8

Introduction

Rayner Mayer described the need to reduce the environmental impact of transport. This included rail as well as road because of the EU objective to shift 30% more freight from road to rail so environmental impact of rail would increase. As the user only paid the marginal rather than the full socio-economic cost, it was not surprising that the mobility of people and goods was still increasing.

Impacts

The project had identified four major impacts through workshops with stakeholders. These are noise, gaseous emissions, damage to the infrastructure and loading through the suspensions of the infrastructure. Research at Empa has shown that the impacts are not equally distributed within vehicle categories and impact types. Although newer road vehicles are less polluting their noise emissions remains to be significant and methods need to be developed to reduce the noise impacts. Furthermore, longer and heavier road vehicles such as platoons pose new imapcts and challenges that need to be addressed. The one EU initiative that would help develop the Ecovehicle label was the development of a model that would allow CO2 emissions from individual vehicles to be calculated. The development of the euro VI engines had significantly reduced emissions of NOx, particles and hydrocarbons for heavy goods and similar developments for passenger engines would follow. So these pollutants would not need to be labelled.

Costs

ARE (Office of Spatial Development) had commissioned an external cost study of transport from Ecoplan. This study identified costs for all transport modes and the major costs for road vehicles were used to select the impacts described above. There were currently three cost categories based on differentiation of gaseous emissions. Empa had proposed a new cost formula based on noise emissions which had yet to be implemented.

SBB will introduce a wear formula which will calculate the track access charge for a given rate and time of day for specific vehicle types, including freight wagons. It was too soon to determine how this might influence load flows. A bonus payment in accordance with the 2008 Green Transport package was being paid by Dutch, German and Swiss railway undertakings to freight owners who operated quiet vehicles, and an additional bonus was paid by the Swiss Authorities if vehicles were fitted with disc brakes.

Regulation and labelling

Dominique Schneuwly (BAFU) described how the EU tyre label had influenced consumer choice and Jean-Dominique Perrot (Michelin) discussed how the introduction of the tyre label had helped Michelin to differentiate their tyres form their competitors. Ulf Sandberg (VTI) discussed the need for more research for improving the tyre label.

Rayner Mayer explained how the successful introduction of the tyre label had led to the idea of proposing an environmentally friendly vehicle label. This would complement existing labels for noise and CO2 emissions and add two further impacts that of fuel consumption and the road or track friendliness of the suspension. Various vehicle classes would be identified in accordance with current classifications for road and rail vehicles. The label would help infrastructure maintainers to offer subsidies to operators of environmentally friendly vehicles.

General discussion

- The concept of an environmentally friendly vehicle label was a good idea

- Its implementation could take much time and effort as good quality data were required and, for the rail mode, new norms and standards would be needed
- The method for measuring noise of road vehicles and allocation of the tyre label should be improved
- The new label concept should be brought to the attention of DG Move and DG Environment and introduced to the labelling committee
- ERRAC and ETRTR should also be informed
- One way of taking the concept forward would be to trial it along one of the nine Green Corridors, preferably the route transiting Switzerland
- New research is needed to assess the environmental impact of longer and heavier road vehicles such as those in platoons

Conclusions

Any initiative to reduce environmental impact of transport should be trialled as the timeline to irreversible changes in climate as short. In any follow-up phase, more stakeholders from more countries need to be involved.

III Ecovehicle Summary of Task 1: Quality check for WIM data

AUTHORS

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ABSTRACT

This paper describes the development of a simple standardised test to assess the quality of the data measured by Weigh-in-Motion (WIM) systems as part of the European EcoVehicle project ∑!7219. First the background, reasons and requirements for such a test are explained. These are followed by an explanation of the starting points and the approach used in the development of the test and its criteria. The individual quality checks and criteria were evaluated using actual WIM data from sites in four different European countries. Finally, a summary is provided presenting the main conclusions and recommendations for the future application of these tests and their potential to serve as a standard data quality assessment tool.

BACKGROUND

The damage caused by the loading of a heavy vehicle on the road – and rail – infrastructure is one of the aspects of a vehicle’s environmental footprint. Road pavements are especially impacted by high axle loads whist road bridges are more affected by high gross vehicle weights (Cebon, 1999). To be able to assess and compare the impact of different vehicles, their individual axle loads and gross vehicle weights need to be determined. Weigh-In-Motion systems are uniquely capable of measuring these actual axle loads and gross vehicle weight whilst the vehicle is in motion (Jacob, 2002).

One of the objectives of the Eureka Footprint project ∑!2486 (Mayer, 2009) was the development of a method to identify vehicles by means of their "Environmental Footprint". These environmental footprints are characterised by dynamic load, displacement within pavement layers, noise and vibration induced by the vehicle. The vehicle footprint can be used firstly to compare the impact of different modes of transportation in terms of their environmental friendliness and secondly for a potential infrastructure charging where all external effects are internalised.

Quality of WIM Data

The quality (accuracy, reliability and stability) of the measurement data used in any study directly determines the quality of the results and conclusions of the study. The WIM data from different European countries used in the Footprint project (Poulikakos, 2009) have shown variability that could not be explained by mere differences in the national loading regulations alone. The differences in the data may have originated from variations in the local traffic flow, the environmental conditions or from differences in performance of the WIM systems, e.g. the type of WIM technology used or, possibly, structural measurement errors.

For a realistic comparison of the environmental impact of different vehicles – and in fact any other study on the impact of heavy truck traffic - the quality of the WIM data must be verified. This is especially important when comparing the effects in different European countries since the measurement data will come from different WIM systems based on different technologies, operating under different conditions and owned by different users. At present there is no uniform European standard procedure to make an assessment of the quality of WIM data from different systems. As a result many studies are based on WIM data with little - if any - idea of the quality of the data and as a consequence some conclusions may be based on erroneous data.

A full guarantee of the quality of WIM data can only be given after an extensive evaluation of the performance of the WIM system, the traffic and environmental conditions over a long period of time (e.g. 1 year). In most cases, such an extensive evaluation is too time consuming, too expensive to carry out and also too complicated since it requires an in depth knowledge of WIM systems and sensor behaviour. A limited and simplified evaluation could fill the gap between an extensive and expensive test and no test at all, allowing for a quick assessment of the quality of the WIM data.

THE ECOVEHICLE E!7219 PROJECT

The goal of this European cooperative project is defining road and rail vehicles with a low environmental footprint (Lees, 2014). The principal tasks include: analysing data from real time measurements, defining limit values for environmental friendly vehicles and defining a combined environmental index for vehicles. An important EU objective is to reduce the environmental impact of transport. Characterising the environmental impact of individual vehicles enables the polluter pays principle to be applied to land transport. This impact can be measured via a sensor array located within or alongside the road.

Objectives

The objectives of this particular part of the EcoVehicle project are:

to develop a limited and simplified evaluation for a quick assessment of the quality of the WIM data;

to provide the first international benchmark on the data quality management, procedures and criteria used by different users of WIM systems in Europe.

It is hoped, this project could lead, in time, to the direction of a harmonised European criteria and procedures for Data Quality Management for WIM systems.

Project Structure

The project was divided into two main work packages, the first work package focused on the assessment of the data quality, whilst the second work package investigated the existing procedures for data quality management from different European countries.

Work Package 1, Data Quality Assessment.

Task 1.1: Determination of the tests and criteria needed to assess adequately the quality of the data;

Task 1.2: Collection of a sample of WIM data (one week of data) from different users, different countries and different technologies;

Task 1.3: Evaluation of the quality and criteria tests for the WIM data from different systems.

Work Package 2, Data Quality Management.

Task 2.1: Create a catalogue of the procedures for the management of data quality from at least four different users of WIM systems in different European countries;

Task 2.2: Examine the effects of calibration, a comparison of the quality of WIM data one week before calibration with that of one week after;

Task 2.3: Summary and assessment of the main similarities and differences.

This paper will describe the results from work package 1.

DATA QUALITY ASSESSMENT

Objective

The objective of this work package was to develop a set of tests and criteria that will allow the user to make a quick verification of the quality of the data from any WIM system in Europe. These tests could then be used to compare the relative quality of different WIM sites (the quality of the data from site A is better than that of site B) and, if possible, to give an indication of the absolute quality of the data of a particular site (the data from site C has a quality that is sufficient).

In general, the tests will look at the stability of certain elements or characteristics of the measured data. The selection of the characteristics was based on an evaluation of international literature on WIM data quality management and the practical experience of both authors.

In case the tests are used to obtain an indication of the absolute quality, the aim was to develop criteria to be able to distinguish between different quality levels. The initial absolute criteria will be derived from the maximum legal limits for international goods transport and values common for certain types of trucks.

Warning

It is important to realise that the quality tests will not be able to distinguish between variations in the measurements by the WIM system and variations in the truck traffic at a certain site. This means that in case the test results would produce an “insufficient” verdict on the quality of data because of large variations in the WIM data, the reason for this could be explained by variations in the traffic flow and not because of the WIM system. In this case, the results of the tests should be interpreted as: “Do not use this data without additional checks on the quality of the data.”

Starting Points

In the development of the checks the following starting points were used:

the tests should give a first indication of the quality of the data measured by a certain WIM system;

the tests should be easy to perform by anybody irrespective of whether they are specialists in Weigh-In-Motion or statistics or not;

the calculations required for the tests should be available – or be easy to implement - in standard software like Excel, Access (or similar);

it should be possible to do the tests on all measurement data from all different WIM systems currently operational in Europe;

the tests will be done on a limited sample from the WIM data only, e.g. one week representative of normal operational conditions. The test sample should be large enough to include possible variations over a few days and be small enough to be handled in Excel.

International experience

In the development of the data quality checks the experience was used from a number of international projects on the quality control of the measurement data from a network of WIM systems. In particular the experience from the USA, South-Africa and the Netherlands were used in this study.

United States, LTPP Program

During the 1980s, the Transportation Research Board (TRB), the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO), undertook a Strategic Transportation Research Study (STRS) of the deterioration of the Nation's highway and bridge infrastructure system. The study recommended that a Strategic Highway Research Program (SHRP) be initiated to focus research and development activities on improving highway transportation. The Long-Term Pavement Performance (LTPP) program was started as one of these activities.

The LTPP program was envisioned as a comprehensive nationwide program for a better understanding of the effects of many variables on pavement performance; and new techniques for pavement design, construction, and maintenance. One of the areas within the program focuses on the effects of traffic loading on pavements, for this a network of Weigh-In-Motion system has been build. The data measured by these WIM systems is collected in a national long-term pavement database.

Experiences in the first years of the program showed that without proper attention the quality of the WIM data varied from one system to another and in many cases was unknown. This resulted in masses of measured data that were not useful for any kind of analysis or study. This has triggered the development of a WIM Data Quality Management system within the LTPP program (FHWA, 2010).

The Netherlands, WIM-NL Network

In 2000, the Ministry of Transport and Public Works in The Netherlands started a project to reduce the overloading by heavy trucks on the NL-highway network. As part of this program a network of 20 WIM systems were built. The systems are used as a pre-selection tool for road side weight controls by the Transport Inspectorate. The measurement data is also stored into a central database and is used by Rijkswaterstaat in the design of new pavements and bridges and the planning of the maintenance of the existing ones.

The Transport Inspectorate also uses the WIM data of all overloaded trucks in combination with the license plate number to identify those transport companies that are responsible for the most overloading. These ‘bad’ companies are subject to intensified controls by the Inspectorate and risk high penalties if they do not improve their behaviour. Crucial element in this enforcement program is that without good quality WIM data this program is certain to fail. That is why Rijkswaterstaat has developed quality control procedures and checks to manage the quality of the WIM data that is provided to the Transport Inspectorate for their enforcement program (Telman, 2013).

South Africa, SANRAL Quality Checks

WIM systems are installed on various highways in South Africa to provide traffic loading information for pavement design, strategic planning and law enforcement. The inherent inaccuracy of the WIM systems sometimes leads to the misinterpretation and misuse of data which may result in imbalances in pavement design and overload control.

Experience has shown that robust and effective tools are required to assess the accuracy and quality of WIM data on a routine basis.

Since early 2000 the South African National Roads Agency Ltd (SANRAL) has started the development of different statistical methods for the calibration and quality assessment of the data from their network of WIM systems. This has resulted in a comprehensive quality management system that has been in operation for several years, and is constantly being innovated.

The method is currently being used for about 50 WIM systems located on the major toll roads in the country, totalling approximately 1.300km of national roads. The most important data quality checking parameters that are used are the standard deviations of truck-tractor and front-axle loads, average front axle loads, stability of calibration factors and the front-axle / truck-tractor load ratios (De Wet, 2010).

Quality checks and criteria

Determination of the tests and criteria to assess the quality of the data. In other words this means finding characteristics of certain types of vehicles that show a very small variation in daily practice and are commonly found throughout Europe. This can either be caused by international regulations for heavy goods vehicles (examples 1 and 2) or by standards in vehicle design (examples 3 and 4). The following examples of such characteristics were used in the quality checks:

The vehicle length of Truck+Trailer combinations and that of Tractor+Semi-trailer (articulated) combinations. For most EU member states the maximum allowable lengths for these combination are respectively 18.75m and 16.50m;

The Gross Vehicle Weight (GVW) of 3 axle Trucks and that of 5 axle Tractor + Semi-trailer (articulated) combinations. For most EU member states the maximum allowable GVW's for these combination are respectively 26ton and 40/44ton;

The axle load of the first (steering) axle of – fully loaded - 5 and 6 axle articulated vehicles. International experience has shown that the load on this axle lies normally in a narrow bandwidth between 6.5 and 7.0 tonnes;

The axle distance between the 2nd and 3rd (driven) axles of 6 axle Tractor + Semi-trailer combinations. International experience has shown that the distance between these axles is very stable at 1.30m as this allows the highest axle loads;

Besides the weight and length related tests, other parameters that should be checked that provide an indication of the correct operation of the WIM system itself:

The variation in the number of registrations per day;

The number or percentage of unclassified vehicles – or classified as 'Other´ - per day;

The number or percentage of measurement or system errors per day;

The number of hours without registration (between 04:00 and 24:00h)

For the first four tests described above, the average values and standard deviation were calculated. The average value can be compared with a reference value to check for the absolute quality, the standard deviation gives a value for the stability of the measurements.

Sample data

The objective was to collect a sample of WIM data (one week of data in case of a WIM-site with high traffic volumes) from different users, different countries and different technologies. The aim was to try to collect more data from different countries, if possible based on different technologies and if possible data from 'good' and 'bad' quality sites to be able to see if the criteria are able to detect the bad data.

For the project, measurement data from two sites in each of four different European countries have been collected and evaluated. We have also deliberately included a ninth site which we knew was not working correctly and therefore providing erroneous data. We have included this site to highlight the value of identifying faulty sites. This site will appear as Site 9 in the graphs and tables.

It should be stressed that in all cases, the exact location of the WIM sites, the type of equipment deployed and the manufacturers have been kept anonymous to ensure any unintentional bias cannot be applied to the results. It was also felt that anonymity of the equipment should be maintained to avoid any unnecessary comparisons between technologies and vendors.

DATA ANALYSIS

Gross Vehicle Weight

As described above, we examined the data from nine European sites using a weeks worth of data and have found that there appears to be a reasonable correlation between sites when certain parameters are examined.

The first vehicle class we looked at was that of the rigid three axled goods vehicles. These are relatively common on European roads and it was felt that this was a reasonable area to start testing.

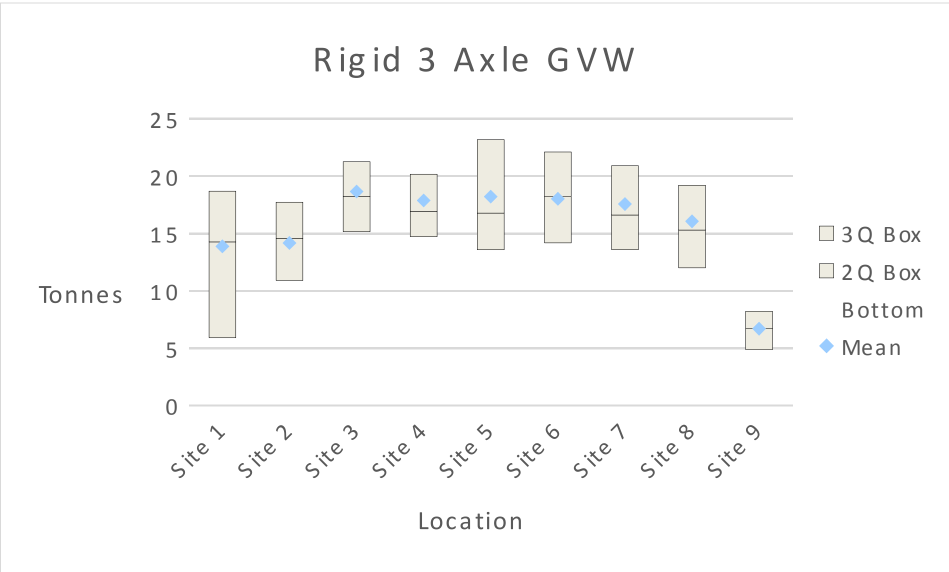

***Figure 10** – Analysis of 3 axle rigid trucks*

***Table 1 –** Overview of 3 axle rigid vehicles*

Site	1	2	3	4	5	6	7	8	9	Average
Mean	13.88	14.17	18.65	17.88	18.21	18.02	17.57	16.06	6.69	15.81
St. Dev.	7.49	6.37	5.50	5.09	6.21	5.31	5.63	5.24	2.22	6.41

The average GVW for three axle rigid trucks is expected to be between the maximum permissable weight (26 tonnes) for this class and the weight of empty trucks (around 10 tonnes). Hence an average value somewhere between 15 and 20 tonnes with a variation of 5 tonnes.

Sites 1 and 2 show a slightly lower average weight and a relatively higher variation. This is a bit suspicious and could generate a warning for a closer examination of the measurements and traffic conditions on these sites. The data from the other sites look alright for this criterion. Except for Site 9 where the average GVW is extremely low and it was known that the data was faulty. This can clearly be seen in both graphical and tabular results from this test.

The second analysis was carried out on the type of articulated goods vehicle that is probably the most frequently encountered vehicles on European roads; the two axle tractor and three axle trailer unit.

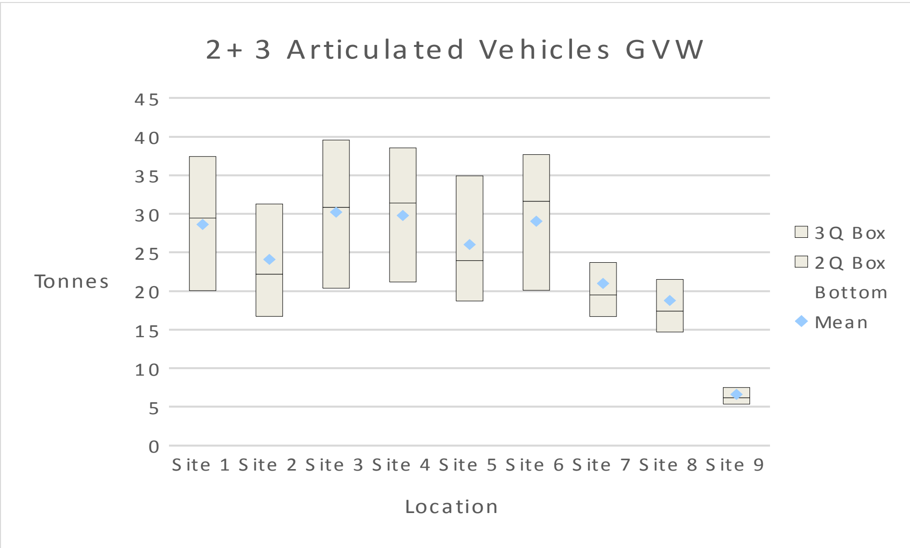

Figure 11 *– Analysis of 5 axle articulated vehicles*

Table 2 – *Overview of 5 axle articulated vehicles*

Site	1	2	3	4	5	6	7	8	9	Average
Mean	28.62	24.09	30.21	29.79	26.02	29.04	20.99	18.78	6.60	28.21
St. Dev.	9.18	8.42	10.19	9.53	8.95	9.55	6.64	5.85	1.94	10.38

The average GVW for five axle articulated trucks is expected to be between the maximum permissable weight (40-44 tonnes) for international transports class and the weight of empty trucks (around 20 tonnes). Hence an average value somewhere between 25 and 30 tonnes with a variation of tonnes. When looking at the chart in Figure 2 it is clear that there is a discrepancy using sites 7 and 8 in any further analysis as the average weights are significantly lower than those seen elsewhere. Whether this is down to a measurement error in the data or local traffic conditions, it is unsure without further inspection.

When combining the results from the analysis of the 3-axle rigid and 5-axle articulated for site 7 and 8; the average weights on the 3-axle class appear in line with others. So the lower average for the 5-axle articulated could be down to local traffic conditions. Again site 9 is clearly erroneous, the average GVW is around 1/3 of what was expected. It should be noted that for the analysis of the gross vehicle weights from the nine sites, we have not removed any outliers in the data as we are looking for any potential anomalies that could influence further analysis.

Steering Axle Load

For the next test we examined the steering axle weight of two axle tractor + three axle trailer articulated tractor+semi-trailer combinations, probably the most frequently used combination on European roads. More specific we examined the axle loads of the first steering axle of these vehicles when fully laden, i.e. in excess of 30 tonnes gross vehicle weight (GVW). Obviously we were reliant on the “accuracy” of the test data to determine whether 30 tonnes GVW was met but this limit is actually not very strict and the results were rather consistent.

For these next two tests it is clear from the previous results that Site 9 would not be able to be tested as none of the records for this vehicle class was measured in excess of 30tonnes.

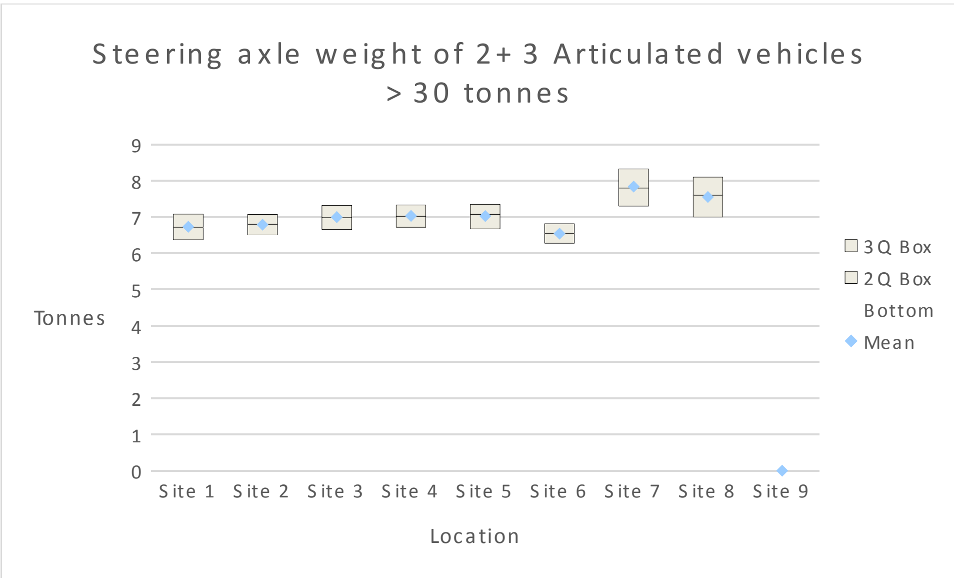

***Figure 12** – Analysis of 1st axle load of five axle articulated vehicles*

***Table 3** – Overview of 1st axle load of 5 axle articulated vehicles*

Site	1	2	3	4	5	6	7	8	9	Average
Mean	6.73	6.79	6.99	7.03	7.03	6.54	7.84	7.55	0	6.97
St. Dev.	0.55	0.44	0.54	0.50	0.52	0.46	0.82	0.74	0	0.55

If site 6 is removed from the analysis, it has some extremes, the mean weight of the steering axle falls within 1 tonne of each other and there appears to be consistency in the 2nd and 3rd quartiles.

Based on international experience the expected value for the first axle load is between 6.5 and 7.0 tonnes with a small variation. The first six sites follow these expectations, while sites 7 and 8 do appear slightly out of line with a higher average axle load and a larger variation. This should then alert the user to perhaps reconsider using the data from those sites in any analyses. Especially when this is combined with the lower average GVW for this vehicle class at these tw, sites.

Again the reason for these difference could also originate from the characteristics of the truck traffic at the site, e.g. a high percentage of light – partially loaded - vehicles that obviously have a lower GVW but tend to have a slightly higher axle load on the first axle because of a different distribution of the loads.

Vehicle Length

In addition to the above two weighing related tests we checked vehicle length, a parameter that is not reliant on the WIM sensors but the inductive loops. This time, again using the same >30 tonne articulated two axle tractor/three axle trailer combination.

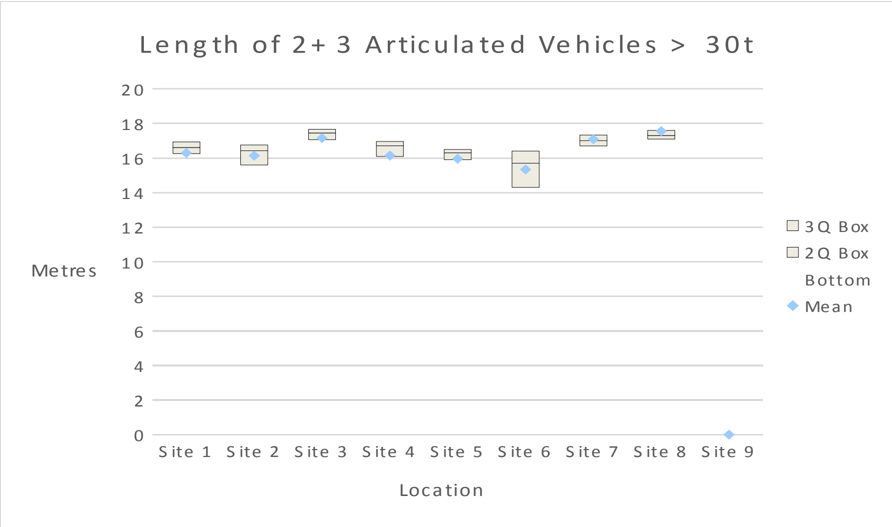

***Figure 13**–Analysis of length of 5 axle articulated vehicles*

***Table 4** – Overview of length of 5 axle articulated vehicles*

Site	1	2	3	4	5	6	7	8	9	Average
Mean	16.29	16.13	17.15	16.14	15.95	15.33	17.09	17.56	0	16.39
St. Dev.	1.03	1.02	0.97	1.40	0.99	1.45	1.03	0.99	0	1.40

The legally permissible maximum length for this type of trucks is 16,5m in almost all EU-member states including the four countries considered in this test. Since transport companies and vehicle manufacturers seek to optimise their vehicles within the legal boundaries it is expected that the average vehicle length will be close to 16,5m with a small variation. The mean lengths of the vehicles across all eight sites is within 1.5 metres which is encouraging and would allow the user to have some confidence in using the data for length and classification purposes.

Although individual vehicles may exceed this maximum value it is unlikely that the average value is higher than the maximum limit. This indicates that the length measurement of all sites is 0.11m less than expected yet it has a small variation. It is interesting to note that sites 7 and 8 exceed the maximum length for this type of vehicle but it is known that data from these two sites were likely to have anomalies due to lack of site maintenance and recent calibration. In all cases, this kind of structural measurement error can easily be compensated through calibration. Only site 6 shows a slightly higher variation but this could originate from the local traffic conditions.

Axle Distance

The tests on the axle distance between the 2nd and 3rd (driven) axles of 6 axle Tractor + Semi-trailer combinations has not been implemented due to difficulties with the limited detail in the vehicle classification in the data from a few of the sites. In other words it has not been possible to filter out this specific vehicle class needed for the test.

Performance Indices

So far we have presented some simple tests on the measurement performance of the different WIM systems that are easily processed using a spreadsheet system. These, when graphically produced, make it easier for the analyst to gain a quick understanding of any potential areas of error when using some sites data. Anomalies are easily identified and these can then be further investigated by drilling down into the data, if so required.

There are a number of indices that give an additional idea of the overall performance of the WIM system. These indices are not related to the primary measurements but to the operational stability of the system.

***Table 5 –** Overview of the test results*

Site	1	2	3	4	5	6	7	8	Average
Percentage Variation in # of registrations	17.6	21.1	9.3	16.9	8.2	11.6	5.9	9.6	12.5
Percentage of unclassified	0	0	< 0.1	<0.1	0	0	< 0.1	< 0.1	< 0.1
Percentage of meas. errors	< 0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
# hours without registrations	43	9	0	0	0	1	0	0	6.63

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CONCLUSIONS

a set of tests and criteria was developed and will allow users to make a quick verification of the quality of the data from any WIM system in Europe;

the tests look at the stability of different characteristics of the data measured by the WIM system;

These tests can be used to compare the relative quality of different WIM sites (the quality of the data from site A is better than that of site B);

These tests can be used to give an indication of the absolute quality of the data of a particular site (the data from site C has a quality that is sufficient);

For this, criteria were developed to assess the absolute quality derived from the maximum legal limits for international goods transport and values common for certain types of trucks;

The criteria are:

***Table 6** – Overview of the test criteria.*

Criterion	Min. Value	Max. Value
Av. GVW of 3 axle rigid	15t	20t
Av. GVW of 5 axle articulated	25t	40t
Av. Steering Axle Load	6.5t	7.0t
Av. Vehicle Length	15.5m	17.5m
Av. Axle Distance	-	-
Variation in # of registrations	●	-
Percentage of unclassified	-	5%
Percentage of meas. errors	-	5%
# hours without registrations	-	5 per week

When applying these tests and criteria to 8 WIM systems from 4 different European countries, the following results were obtained:

***Table 7 –** Overview of the test results*

<table>
<tr><th>Site</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th></tr>
<tr><td rowspan="2">Remarks</td><td colspan="2">Low GVW for 3 axle rigid trucks</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="2">High 1st axle + low GVW for 5 axle semi-trailers</td><td>Extremely low GVW for 3 axle and 5 axle trucks</td></tr>
<tr><td colspan="2">Many hours without registrations</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="2">High average vehicle lenght</td><td></td></tr>
<tr><td>Result</td><td colspan="2">Warning, do not use data without further analysis.</td><td colspan="4">OK, data can be used without further analysis.</td><td colspan="2">Warning, do not use data without further analysis.</td><td>Error, do not use this data!</td></tr>
</table>

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RECOMMENDATIONS

Since the outcome of the test is sensitive to the choice of what week of data is used. The selected weeks should represent normal operational conditions. Weeks with known variations due to holidays, road works or extreme weather conditions should be avoided.

In case of a negative result of these tests this should be interpreted as: “Do not use this data without additional checks on the quality of the data.”

In case of a positive result this should be interpreted as: “There are no reasons to suspect the quality of this data however this is not a guarantee”;

By repeating the tests on data of one system from a number of different weeks from different periods over a year, the results of the will give a more reliable indication of the actual performance of the system.

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Glossary

Abbreviation	Meaning
ARE	Bundesamt für Raumentwicklung, Swiss federal office of spatial development
CHF	Swiss Francs
EC	European Commission
EZV	Eidgenösische Zoll Verwaltung, Swiss federal tolling office
GHG	Greenhouse gases
HDV/HGV	Heavy duty vehicles/Heavy goods vehicles
HVC	Heavy vehicle charge
LSVA	Swiss heavy vehicle charge
Rp	Rappen= Swiss cents
UBP	Umweltbelastungspunkte, Eco Points
WHO	World health organisation

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Project Conclusion Form

FORSCHUNG IM STRASSENWESEN DES UVEK

Version vom 09.10.2013

Formular Nr. 3: Projektabschluss

erstellt / geändert am: 19.04.2017

Grunddaten

Projekt-Nr.: ASTRA 2014/001

Projekttitel: Schweizer Beitrag zum Eureka Projekt Ecovehicle E!7219

Enddatum: April 2017

Texte

Zusammenfassung der Projektresultate:

Greater demands on the road transport infrastructure as a result of economic growth have manifested themselves in an increase in the number of Heavy Duty Vehicles (HDV) worldwide. This increase is inherently accompanied by increase in congestion, noise, energy use and pollutant emissions as well as an increase in the infrastructure overuse. For a sustainable transport infrastructure, comprehensive instruments are needed in order to encourage vehicles with a low environmental footprint. The Swiss heavy vehicle charge (HVC) (Leistungsabhängige Schwerverkehrsabgabe or LSVA) has been introduced in order to internalize the external costs of HDVs by introducing a variable charge based on the engine polluting potential or EURO categories and transport performance. However, as the trend shows, vehicles belonging to polluting EURO categories are rapidly replaced by clean vehicles, the differential charging currently implemented by the LSVA does not fulfill the intended goals of recovery of the external costs of road transport in the longer term. Especially since the current differential charging categories are purely based on pollutant emissions but external costs are also produced by other effects such as noise and damage to infrastructure. Previous research by the authors has shown that the newer vehicles are not necessarily less noisy. Therefore the current instruments do not encourage low noise vehicles and new instruments need to be developed to encourage these.

This project aimed to relate the environmental footprint of heavy duty vehicles to external costs incurred by such vehicles. To this end, the external costs of transport reported by the report from ARE from noise, gaseous emissions and dynamic load was used. This data was related to the individual impact of each vehicle using data collected from a Swiss monitoring site in Oberbuchsiten between Zurich and Bern to estimate the external costs of individual vehicles. To this end, using a data set the cost of noise, emissions and damage to infrastructure was calculated for Swiss heavy vehicle categories. The data shows that in each category there are vehicles with high impacts and therefore costs and those with low impacts demonstrating the potential for improvement in each vehicle category. Noise and emissions impacts were added using Eco-points (UBPs) to demonstrate the environmental effects of heavy vehicle categories.

Three noise emission models for highway speed regimes were developed and expanded to demonstrate the effect of using low noise tyres using the noise data obtained at the Oberbuchsiten site in 2011 using the following parameters: vehicle classification, number of axles and maximum allowable weight. Furthermore, the noise model was expanded for an urban speed regime (<50km/h).

One of the instruments in reducing traffic noise is the tyre and therefore the low noise tyres currently available are of particular interest for this project. The variance in noise emissions of the available tyres currently on the market (>3 dBA) shows that there is a great potential to lower traffic noise by using low noise tyres. Five scenarios were developed in order to introduce a noise bonus of 30% or 50% of the LSVA for 10 % of the tonne-kilometers transported demonstrating the hypothetical gain or loss of revenue of maximum 5% in comparison to the status quo (01.01.2017). The current limited in situ data indicates that more research needs to be carried out verifying the in-situ noise emissions of low noise tyres.

In a series of workshops with stakeholders, the major environmental impacts have been identified and reviewed. These are –

- fuel consumption
- carbon dioxide emissions
- damage to the pavement or track
- audible noise

and it is proposed to capture this vehicle information in an EU-type label. By bringing these impacts together it will enable the buyers to purchase a vehicle which meets their needs and is also environmentally friendly. It could also provide a basis for applying road usage or track access charges and for internalising some of the external costs currently carried by society.

Zielerreichung:

The goals set forth by the project were achieved as follows:
1.Three noise emission models for highway speed regimes were developed
2.The environmental footprint of heavy duty vehicles to external costs incurred by such vehicles
3. Five scenarios were developed in order to introduce a noise bonus in the LSVA
4. In cooperation with European partners eight workshops were organised to bring together various national and international stakeholders also from outside the project

Folgerungen und Empfehlungen:

1.In each vehicle category there are vehicles with high impacts and therefore costs and those with low impacts demonstrating the potential for improvement in each vehicle category.
2. There is a great potential to lower traffic noise by using low noise tyres.
3. More research needs to be carried out verifying the in-situ noise emissions of low noise tyres.
4. Five scenarios were developed in order to introduce a noise bonus of 30% or 50% of the LSVA for 10 % of the tonne-kilometers transported demonstrating the hypothetical gain or loss of revenue of maximum 5% in comparison to the status quo (01.01.2017).
5. Any change to the LSVA should consider the fact that the various parameters considered in this report are influencing the infrastructure and the environment differently for example less axles results in less noise, at the same time transporting the same tonnage on less axles causes more damage to the infrastructure and any charging scheme should not encourage vehicles with less axles such as delivery trucks (Lieferwagen).

Publikationen:

1. Poulikakos, L.D., Mayer, R.M., Heutschi, K., Soltic, P., Lees, A., Van Loo, H.: Defining road and rail vehicles with a low environmental footprint. Transport Research Arena, TRA 2016, Warsaw.
2. Poulikakos, L D, Heutschi, K, Soltic, S., Del Duce, Andrea. Relating impact of heavy vehicles to the external costs. International Conference on Weigh in Motion, ICWIM7 2016, Foz de Iguazu Brazil.
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4. Poulikakos, L.D., Heutschi K., Soltic, P., Del Duce, A. Relating the environmental impact of heavy duty vehicles to the external costs and Eco-Points induced through road transport, submitted

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Unterschrift des Projektleiters/der Projektleiterin:

Lily Poulikakos

FORSCHUNG IM STRASSENWESEN DES UVEK
Formular Nr. 3: Projektabschluss

Beurteilung der Begleitkommission:

Beurteilung:

- The aim of this follow up project iwas to develop new instruments to encourage vehicles with a low total footprint. Specifically, to develop methods to include noise as a parameter in the differential charging of LSVA. This will be achieved in parallel within a new European Project Eureka Ecovehicle (E!7219).
- Die Ziele wurden erfüllt. Die in der Projektbeschreibung vom 17.12.2013 enthaltenen "Swiss contributions" wurden geleistet, mit Ausnahme eines Beitrags zu Task 2 ("Methods of Informing Operators"), weil dieser Teil im Gesamtprojekt aufgegeben wurde. Nicht behandelt wurde die Auswirkung verschiedener Beläge in Task 3, dafür wurde ein anderer Projektteil vertieft. Untersucht wurden die umweltbezogenen Auswirkungen des Fahrzeugbetriebs. Offen ist die Präsentation der Ergebnisse in einem geeigneten Rahmen, was nach Freigabe der Forschung durch die Auftraggeber erfolgen kann. Die zeitlichen Vorgaben wurden ebenfalls eingehalten, die Vernetzung ins internationale Projekt war sehr gut.
- Beim Fahrzeuglärm bestehen keine eindeutigen Unterschiede zwischen den Schwerverkehrskategorien, so dass eine Bewertung nach diesen nicht möglich ist. Wesentlicher Unterschied ist die Art der Bereifung. Ein Abgabesystem könnte dort ansetzen. Mit dem Bericht wurde eine Grundlage geschaffen, die erlaubt zu diskutieren, ob die Lärmproblematik über eine Anpassung in der Tarifierung via Pneu-Labels oder über Vorschriften bei Neufahrzeugen oder dem Vertrieb von Reifen angegangen werden soll.

Umsetzung:

Die Untersuchungen liefern einen Beitrag für eine Weiterentwicklung der LSVA. Dabei wurde auch die Erhebungsmöglichkeit geprüft und ein neuer Ansatz für den Einbezug des Fahrzeuglärms über die Art der Fahrzeugbereifung dargestellt. Erhebungen zum Lärmaspekt müssten vermutlich ausserhalb der LSVA-Methodik gefunden werden. Zum Ziel „Umweltfussabdruck des Strassenschwerverkehrs“ wird der Einbezug des Lärm und der Strasseninfrastrukturschäden hergeleitet und in den Fussabdruck eingerechnet.

weitergehender Forschungsbedarf:

- Die Messungen erfolgten auf einer Autobahn, Messungen im städtischen Bereich wären eine wertvolle Ergänzung.
- Die auf Selbstdeklaration beruhenden Angaben zum Reifenlärm sollten mit Messungen überprüft werden.

Einfluss auf Normenwerk:

Kein direkter Einfluss

Der Präsident/die Präsidentin der Begleitkommission:

Name: Gantenbein Vorname: Andreas

Amt, Firma, Institut:

Unterschrift des Präsidenten/der Präsidentin der Begleitkommission:

Forschung im Strassenwesen des UVEK: Formular 3 Seite 3 / 3

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