



National Institute
for Public Health
and the Environment

Report 680300009/2010
E.N.G. Verheijen | J. Jabben

Effect of electric cars on traffic noise and safety

RIVM letter report 680300009/2010

Effect of electric cars on traffic noise and safety

Edwin Verheijen
Jan Jabben

Contact:
Jan Jabben
RIVM MEV/CMM
Jan.Jabben@RIVM.nl

This investigation has been performed by order and for the account of the Ministry of Housing, Spatial Planning and the Environment (VROM DGR-LOK), within the framework of the project 'Beleidsondersteuning Geluid', number M680300

© RIVM 2010

Parts of this publication may be reproduced, provided acknowledgement is given to the 'National Institute for Public Health and the Environment', along with the title and year of publication.

Abstract

Effect of electric cars on traffic noise and safety

In urban traffic, cars with electric engines are not only cleaner but also less noisy than cars with internal combustion engines. In particular this applies for speeds up to 20 kilometers per hour. A fully electrified fleet will be 3 to 4 dB more silent compared to the present fleet. The number of people severely annoyed by traffic noise will be reduced by one third. However, it will last at least until 2030 before there are enough electric cars to realize this noise reduction.

Compared to hybrid cars, that use both an internal combustion engine and an electric engine, fully electrified cars are 1 to 2 decibels more quiet. At speeds above 50 kilometers per hour, electric and hybrid cars are not quieter than conventional cars. This is because the tire-road noise increases with speed and becomes the dominant noise source.

Silent cars may lead to increased traffic safety risks, especially to the blind and visually-impaired. Because hybrid or electric cars are less likely to be noticed in traffic, they may pose danger. In the United States of America an analysis of crash records has shown that hybrid cars are involved relatively more often in crashes with pedestrians and bicyclists than do conventional cars. This only occurs in situations where the driving speed is low, such as backing up and parking maneuvers. Up to now, analysis of traffic accidents in Japan and the Netherlands has not shown increased risks for silent hybrid cars.

In the United States and Japan, minimum noise requirements are now being considered. Slowly driving silent cars would then have to produce warning sounds continuously. If minimum noise levels will become compulsory for the European car market, the prospects of less noise annoyance are restricted.

Key words:

noise measures, traffic, hybrid, electric, annoyance, crash, risks, silent

Rapport in het kort

Effect van elektrische auto's op verkeerslawaaï en veiligheid

In stadsverkeer zijn auto's met elektromotoren niet alleen schoner maar ook stiller dan auto's met verbrandingsmotoren. Vooral bij snelheden tot 20 kilometer per uur is het geluidverschil substantieel. Een volledig wagenpark met elektromotoren kan in een stedelijke omgeving 3 tot 4 decibel minder geluid veroorzaken ten opzichte van de huidige situatie. Het aantal mensen dat last heeft van verkeersgeluid neemt dan met een derde af. Het zal echter nog minstens tot 2030 duren voordat er voldoende elektrische auto's zijn om deze geluidafname te kunnen realiseren. Dit blijkt uit onderzoek van het RIVM.

In vergelijking met hybride auto's, die naast een elektromotor nog een verbrandingsmotor hebben, zijn volledig elektrische auto's 1 tot 2 decibel stiller. Bij snelheden boven 50 kilometer per uur maken elektrische en hybride wagens evenveel lawaai als conventionele wagens. Dat komt doordat het bandwegdekgeluid met de snelheid toeneemt.

Het stille karakter brengt mogelijk extra risico's mee in het verkeer, vooral voor blinden en slechtzienden. Doordat hybride of elektromotoren minder opvallen in het verkeer, kunnen ze gevaarlijke situaties opleveren. In de Verenigde Staten heeft een analyse van ongevallenregistraties uitgewezen dat hybride auto's relatief vaak betrokken zijn bij aanrijdingen van voetgangers en fietsers; bij elektromotoren is dat nog niet onderzocht omdat ze nog weinig worden gebruikt. Het gaat hierbij alleen om situaties waarin langzaam gereden wordt, zoals bij achteruitrijden en parkeermanoeuvres. In Nederland en Japan zijn tot nu toe geen statistische aanwijzingen gevonden voor een verhoogde kans om door stille hybride auto's te worden aangereden.

Vanwege de mogelijke risico's wordt in de Verenigde Staten en Japan gewerkt aan voorstellen om minimum geluideisen voor motorvoertuigen te verplichten. Langzaam rijdende stille motorvoertuigen zouden dan – permanent – kunstmatige geluiden moeten voortbrengen om aan de regels te voldoen. Als zulke eisen voor de Europese markt verplicht worden gesteld, zal dit de vooruitzichten op minder geluidhinder inperken.

Trefwoorden:

geluidsmaatregelen, verkeer, hybride, elektrisch, geluidshinder, aanrijding, risico's, stil

Contents

Summary	6
1 Introduction	7
1.1 Current fleet composition	7
1.2 Future fleet composition	8
2 Reduction of Noise and Annoyance	9
2.1 Introduction	9
2.2 Effect on noise annoyance	10
2.3 Effect of mobility growth	11
3 Consequences for Traffic Safety	13
3.1 International Findings	13
3.2 Research in the United States	14
3.3 Research in Japan	14
3.4 Accidents in the Netherland	15
3.4.1 Analysis of car accidents in the Netherlands	15
3.4.2 Reactions on the internet	16
3.4.3 Prediction of response time	17
3.5 Discussion	17
4 Conclusion	19
References	21
Appendix 1 Engine noise and tyre-road noise	23
Appendix 2 Input for urban noise calculation	24
Appendix 3 Results noise calculation	26
Appendix 4 Traffic accidents	27

Summary

Cars using an electrical engine are more silent than petrol or diesel driven engines. In particular this applies for speeds up to 20 km/h. Moreover, cars with fully electrified power are 1 to 2 dB more silent than hybrid powered cars that use a combination of an electrical and conventional engine. At speeds above 50 km/h, the tire road noise becomes dominant and there is no difference in noise emission.

In previous RIVM research it was found that in urban areas, a fleet consisting of hybrid cars could reduce average noise levels by approximately 2 dB and reduce annoyance effects by 20 %. The current study focuses on the possible effects of a fully electrified fleet.

A fully electric car fleet will reduce average urban noise levels by 3 to 4 dB and reduce annoyance effects by more than 30%. However, it is expected that the present fleet will not be sufficiently electrified before 2030.

A fleet consisting of hybrid or fully electrified cars possibly involve extra traffic risks for pedestrians, especially the visual-impaired, and bicyclists due to the absence of engine noise in combination with the absence of tire-road noise at low speeds. In the United States, analysis of traffic accidents showed that in relatively many cases hybrid cars were involved in low speeds crashes with pedestrians or bicyclists. Up to now, analysis of traffic accidents in Japan and the Netherlands has not shown increased risks.

In the United States and Japan, it is now considered to compel manufacturers of hybrid- and electrical cars, or other type of cars whose silent character may lead to extra traffic risks, to install an artificial warning sound. This is probably done by setting minimum requirements for the noise levels of all types of motor vehicles. A Japanese governmental board is evaluating different warning sounds. If minimum noise requirements for cars are also introduced in Europe, this would reduce the future prospects of less annoyance due to traffic noise. As noise annoyance causes health problems, it is recommended to investigate other safety measures than minimum noise levels or continuous warning sounds.

1 Introduction

Electrical and hybrid¹ motor vehicles are very silent, in particular at low speeds. In previous RIVM research [1] it was found that in urban areas at speeds below 50 km/h, a fleet consisting of hybrid cars could reduce average noise levels by 1 to 3 dB. At higher speeds above 50 km/h, the tire-road noise becomes dominant and there is no difference in noise emission. This means that at motorways noise emissions of hybrid and electrical cars will show no significant reduction in comparison with cars solely driven by an internal combustion engine.

In this study we look at the effects of a fully electrified car fleet on the average noise levels in the urban environment. Apart from noise levels and annoyance effects we also look at traffic safety, because the absence of engine noise at low speeds could involve additional incidence risks for pedestrians and bicyclists.

1.1 Current fleet composition

The number of hybrid- or electrical driven vehicles is increasing rapidly in the Netherlands. The use of these vehicles is stimulated by the Dutch government. The trend is depicted in Figure 1. Although the Netherlands, with 4% hybrids of all newly sold cars, can be regarded as market leader in Europe [2], hybrid cars so far only constitute 0.3% of the Dutch car fleet in 2009. This portion is expected to increase significantly in the next years, as more manufacturers emerge on the market and because improved and more luxurious models are developed. This trend is led by the United States and Japan. In Japan 12% of all newly sold cars is now hybrid [3]. These figures all apply to passenger cars. The development of hybrid or electrical freight vehicles or buses is still in early prototype phase.

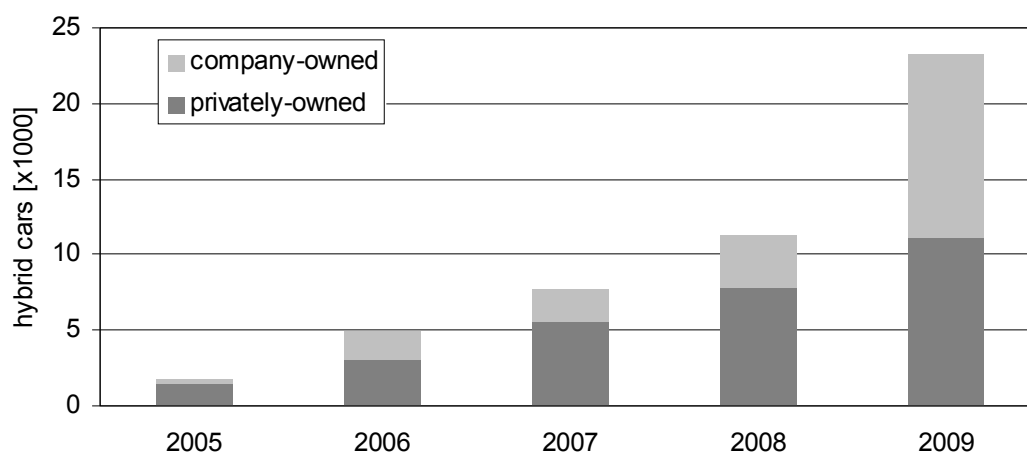


Figure 1: Number of hybrid cars in the Netherlands on January 1st of each year. Taken from [4].

¹ Hybrid cars use a combination of electric and conventional engines. At low speeds the car is driven by an electric unit powered by batteries. At high speeds the extra power is provided by a (more or less conventional) internal combustion engine.

1.2 Future fleet composition

In order to have a significant effect on the average noise emission, the major part of the current conventional fleet will have to be converted into a hybrid or a fully electrified fleet. It will take considerably time before this is the case. In the following, the time that this process will take is evaluated.

Current vehicles are in service during an average period of fifteen years [5]. This is shown in Figure 2. Newly sold conventional cars in 2010 will therefore be part of the cars fleet until 2025. Assuming no change in the current life cycle and extrapolating the current growth rate of hybrids, in 2025 we calculate that hybrid cars could constitute 67% of the Dutch passenger car fleet. Only by 2032 the fleet would consist of 90% hybrid cars and emit significant less noise than the current fleet.

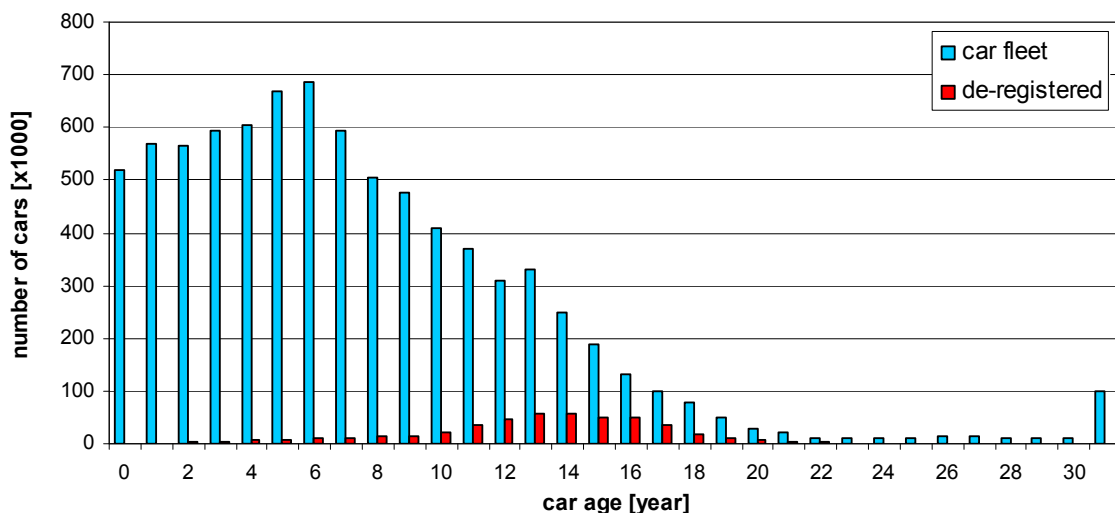


Figure 2: Composition of Dutch car fleet by car age, and age of de-registered cars, in 2005. Source: [5].

A transition towards a fully electrified fleet will take even longer. The Netherlands Environmental Assessment Agency (NEAA) estimates that ‘somewhere between 2020 and 2040’, electrical cars will be profitable for the user [6]. At the moment they are still more expensive than conventional cars. In view of this point, NEAA expects that the amount of electrical passenger cars in the Netherlands will not be significant before 2050. As for heavy trucks NEAA considers fully electrical powering as unrealistic, but in urbanized areas this category will constitute only some 2 % of the total traffic. According to NEAA, ‘the local distribution of goods will be carried out by electrical powered delivery vans and small light weight trucks’

The Netherlands Society for Nature and Environment (NSNE) has a more progressive outlook on the moment that electric vehicles form a substantial part of the Dutch car fleet [7]. Under suitable stimulating policies NSNE proclaims one million electrical passenger cars in 2020, which is approximately 12% of the size of the current Dutch car fleet.

This seems somewhat overoptimistic. In any case ‘suitable stimulating policies’ will play a major role in obtaining a significant transition. From autonomous development only, no large growth of electric vehicles can be expected in the coming decade.

2 Reduction of Noise and Annoyance

2.1 Introduction

Hybrid cars are more silent than conventional cars, in particular at speeds below 30 km/h, where the vehicle is powered electrically. Above 30 km/h, the noise reduction of the hybrid car as compared to a conventional car diminishes rapidly. Firstly because the car switches from electric mode to the internal combustion engine above approximately 20 km/h. Second reason is that the tire-road noise (equivalent for both car types) starts dominating the sound emission above 30 km/h. Above 50 km/h there is no significant difference in noise emission left.

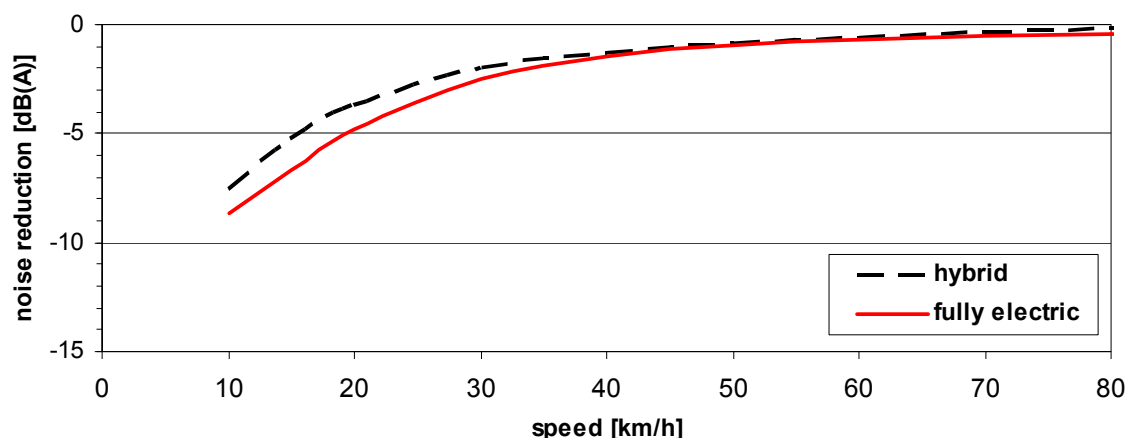


Figure 3: Noise reduction of hybrid and electric passenger cars compared to conventional passenger cars.

Figure 3 shows the noise reduction of hybrid and electrical cars with respect to the total noise emission (engine and tire-road noise) from conventional cars. As compared to hybrid vehicles, the noise reduction of a fully electric fleet will be a little higher, because engine noise is almost absent². Also for electric vehicles, tire-road noise becomes dominant with increasing speed, so that there is no significant noise reduction left above approx. 50 km/h, with respect to conventional cars left.

The noise reduction of the hybrid type in Figure 3 is based on measurements carried in 2008 out by DGMR [1]. For electrical cars, we relied on a recent publication by M+P, in which emission data from the IMAGINE project were presented [8]. The paper specifies the contribution of the engine noise and the tire-road noise at different speeds, see Appendix 1.

² The engine noise of fully electric cars does not completely vanish, but is much lower than for conventional cars. We assumed a reduction of engine noise of 10 dB.

2.2 Effect on noise annoyance

A lower noise emission of vehicles is expected to reduce annoyance effects. The effect of a lower noise emission of passenger cars in a large urban area was estimated using noise maps obtained with RIVM noise mapping software [9]. The maps were determined for the city of Utrecht in the Netherlands. Traffic intensities were estimated based on the road type. This is less accurate than counted data, but since we are only interested in the differences between effects from electrical and conventional cars, such an approach is acceptable. The premises for the calculations are outlined in Appendix 2. In the modeled future scenario, we assumed that 90% of the light passenger cars and light-freight cars is electrified, while 80% of the heavy trucks is electrified. As in our previous study, possible changes in the modal split and the population density were not taken into account. Consequences of mobility growth are discussed in Section 2.3.

Figure 4 shows the reduction of noise levels in a square area covering the city of Utrecht. Figure 4a is taken from our previous study on the effects of hybrid vehicles and can be compared to Figure 4b, which shows the same map with noise reductions to be expected from fully electrified vehicles.

The reductions are shown with respect to the noise levels from conventional cars.

The highest reductions up to 4 dB can be found along the secondary urban roads and at crossings. At the main roads, the reduction is lower, because here the average speed surpasses 50 km/h, so that tire-road noise becomes dominant and reduction of engine noise has no effect on the noise levels. The overall noise reduction is approximately 3 dB.

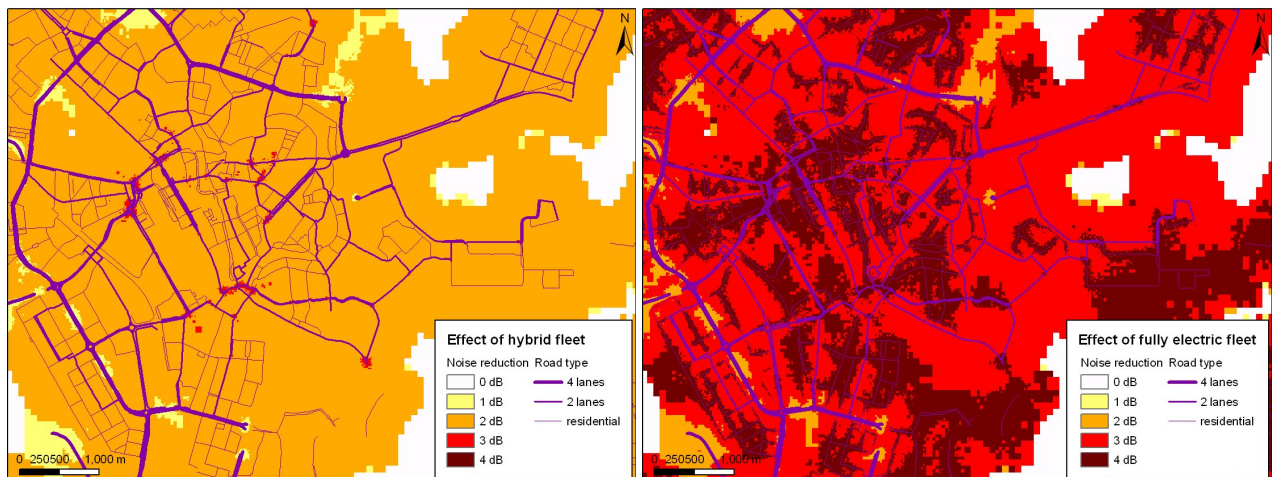


Figure 4a and b: Noise reduction in the town of Utrecht due to hybrid fleet (left) and fully electric fleet (right).

Combining the noise maps with geographical population data, a histogram was obtained containing the number of exposed inhabitants for separate L_{den} values ranging from 30-80 dB. Using the histogram data with the dose-response relationships for road traffic noise [10], the number of annoyed and severely annoyed inhabitants was determined. The results are given in Appendix 3. A transition of a conventional fleet to an electric fleet will lead to a reduction of the number of annoyed inhabitants of 33% and of the severely annoyed by 36%. This is a relatively large effect, which can be considered an important additional reduction compared to the effect of hybrid cars (20% reduction of annoyance, see reference [1]).

2.3 Effect of mobility growth

The noise maps were determined without accounting for mobility growth. A transition to a fleet containing 90% hybrid and electric vehicles may be possible by earliest in 2030, see Section 1.2. A mobility growth of 20% is predicted between 2010 and 2020, see reference [11], which would cause an increase of traffic noise emission with approximately 1 dB. For the period between 2020 and 2040, reference [11] describes four different future scenarios that vary between a slight decrease and a slight increase of traffic volumes. So here no significant further changes in noise emission due to changing traffic volumes is to be expected.

Taking into account an increase of noise emission due to increased mobility, the net effect of a fleet consisting of 90% electric vehicles in 2030 is estimated at approximately 2 to 3 dB. For further reductions, additional noise measures such as more silent tires, silent road pavements or 30 km/h speed zones are needed.

3 Consequences for Traffic Safety

3.1 International Findings

The question whether cars can be too silent, thereby endangering the safety of pedestrians and bicyclists, was raised by organisations of the blind and visually-impaired in Japan and the United States. In Japan, the government considers compelling an artificial sound warning system for silent vehicles [12]. This is further addressed in Section 3.3.

In 2008 a number of hearing tests was done in the United States. The tests were commissioned by the American National Federation for the Blinds (NFB) in order to evaluate risks at crossings and parking lots from the perspective of blind or visually-impaired people. During the tests the human response time of approaching hybrid cars were compared with those for conventional cars [13]. This was done in a laboratory using sound recordings. It appeared that the distance at which a person was able to determine the driving direction of a hybrid car is four times smaller than for a conventional car. The researchers concluded that hybrid cars operating in electric mode may pose substantial risks to blind people, and also to other pedestrians in cases of poor visibility³. They also suggest the use of a modest sound warning system [14,15] as in Figure 5.

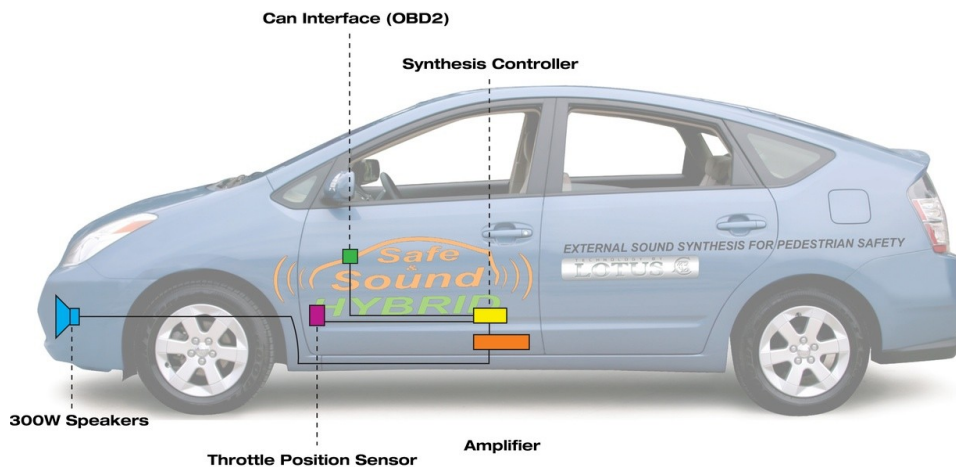


Figure 5: Lotus exterior sound system. Source: [15].

In response to the findings of the NFB, German and Swiss federations for the blind concluded that further research was needed for the European situation [16]. The Dutch network lobby organization for the visually-impaired, Viziris, also expressed their concern. Viziris prefers solutions like better design of pedestrian crossings and the use of detection systems (like radar) to warn pedestrians [17].

³ This not only applies for visually-impaired people, but can also occur with obstacles like parked vans, and during fog.

3.2 Research in the United States

On a hearing of the American National Highway Traffic Safety Administration (NHTSA) it was concluded that in the six deadly traffic accidents with blind in 2007, no hybrid or electric cars were involved [18].

According to the NFB however, relatively more *near-accidents* with blind and hybrid vehicles *do* occur. Therefore the NFB argued for the regulation of a minimum noise emission for hybrid and electrical vehicles [19]. NFB have now lobbied successfully at the American Congress for new legislation that protects pedestrians against incidence risks from silent vehicles [20]. In three or four years time, the efforts of NFB may indeed result in setting a minimum noise emission for new cars in the United States.

The NHTSA found over the period 2000-2007 that, under certain conditions, hybrids had higher incidence rates than normal cars in crashes with pedestrians and bicyclists [21]. Their research was based on American crash files, using 8,387 hybrid cars and 559,703 peer cars with internal combustion engines⁴. Under circumstances where cars drive slowly (stopping, backing up and parking maneuvers) the hybrid cars were two times more likely to hit a pedestrian or bicyclist than were the conventional cars. The researchers stress that though the sample size is still rather small, and larger samples sizes would provide a better estimate of the problem, the results are statistically significant.

This statistic evidence does not explain, however, to what extend the absence of engine noise of hybrids is responsible for the high number of pedestrian crashes. It is then remarkable that the sample has not been corrected for the share of the hybrid cars in the total car mileage. Also, the effect of the difference in population composition between hybrid car owners and conventional car owners was not controlled. Only the number of crashes with pedestrians and bicyclists has been compared to the total number of crashes, for hybrids and normal cars, respectively. That besides lack of engine noise also mileage and driving behavior are important parameters is suggested by a preliminary analysis of an American insurance company [22]: owners of hybrid vehicles drive 25 percent more miles. They also submit more accident claims than owners of non-hybrids, but this can also be explained by the fact that hybrid drivers live more often in cities, while it is known that ‘urban drivers generally receive more traffic citations’.

3.3 Research in Japan

Though there is no evidence in Japan that hybrid cars cause more accidents involving pedestrians [23], there is great concern that blind and visually-impaired people are exposed to higher risks due to the absence of engine noise. Because of this, a study committee at Ministry of Land, Infrastructure, Transport and Tourism is developing guidelines for the audibility of electric and hybrid cars [24]. The research results are presented on a regular basis at the World Forum for Harmonization of Vehicle Regulations of the United Nations.

Field tests revealed the speed at which the audibility of hybrid cars was the same as that of cars with an internal combustion engine. Only below 20 km/h there was a substantial difference in audibility of cars approaching the subjects from the back. Hybrid cars were perceived later than conventional cars. However, when the background noise was raised (artificially), the differences in audibility vanished gradually. In a second test, subjects were asked to judge different artificial warning sounds for slowly

⁴ The conventional cars were selected based on similarity (make, type) with the hybrid ones.

approaching hybrids. As warning sounds may cause annoyance, besides the audibility for pedestrians also the acceptability of the sounds with respect to environment was an important question. Therefore different sounds at different levels were judged, both by subjects outdoors and indoors. Subjects appeared to prefer non-steady sounds and simulated engine noise. The level of some non-steady sounds could be 10 dB(A) less than engine noise without loss of perceivability. An important remark from visually-impaired people was that they should be familiar with the sound as coming from a car. This does not imply that only simulated engine sounds can be used, as artificial sounds can be promoted by publicity campaigns.

An important decision is still to be made by the Japanese government: will the warning sound be voluntary or mandatory? A voluntary sound for cars would be the equivalent of a bicycle bell or a tram bell. A mandatory sound means that sounds are permanently present, at least at low driving speeds.



Figure 6: Publicity workshop in Japan, where visually-impaired had to raise their hands as soon as they heard the approaching car. Augustus 2009, [23].

3.4 Accidents in the Netherlands

The question whether hybrid motor vehicles lead to more accidents at low speeds in the Netherlands cannot be answered yet by statistical research. According to the Institute for Road Safety Research (SWOV) the share of hybrids in the current vehicle fleet is still too small [25]. Electric or hybrid cars were involved in only 230 out of 140,000 vehicle accidents⁵ in 2008 (0.2 %) [26]. In the next section we examine the available data and the problems of analyzing these data.

3.4.1 Analysis of car accidents in the Netherlands

Only seventeen out of the 230 hybrid car accidents were crashes between a hybrid and a pedestrian or bicyclist. As an alternative to statistical analysis, we examined the police reports of these seventeen accidents one by one, see Appendix 4. In these reports we have found no evidence that supports the idea that due the quiet nature of hybrids at low speeds, pedestrians and bicyclists are more likely to get hit by them. However, two remarks should be made by this conclusion. Firstly, in view of the brief

⁵ exclusive of motorway accidents.

reporting format used by the police, it is questionable if such evidence can be found at all in the description of accidents. Secondly, accidents at low speed will not lead to much damage or injuries. In those cases, the road users involved will not always call the police.

The statistical problem (lack of hybrids) can probably be solved by looking at a larger sample of relatively quiet cars. Not only hybrids are quiet at low speeds. If moderate background noise is present, like in built-up or urban areas, also some conventional cars may be silent enough to be heard. The question is then, which car types are relatively quiet? Unfortunately, one cannot use the registered type testing noise level of motor vehicles [27] to answer that question. We have demonstrated earlier that there is no relationship between the type testing data and the actual noise emission measured in urban practice [28], see Figure 7. This is due to the fact that the type test (Directive 70/157/EC) is based on extraordinary driving conditions (full throttle). Cars will produce different amounts of noise under other circumstances. This means that a large measurement campaign would be needed to determine conventional cars that are relatively silent.

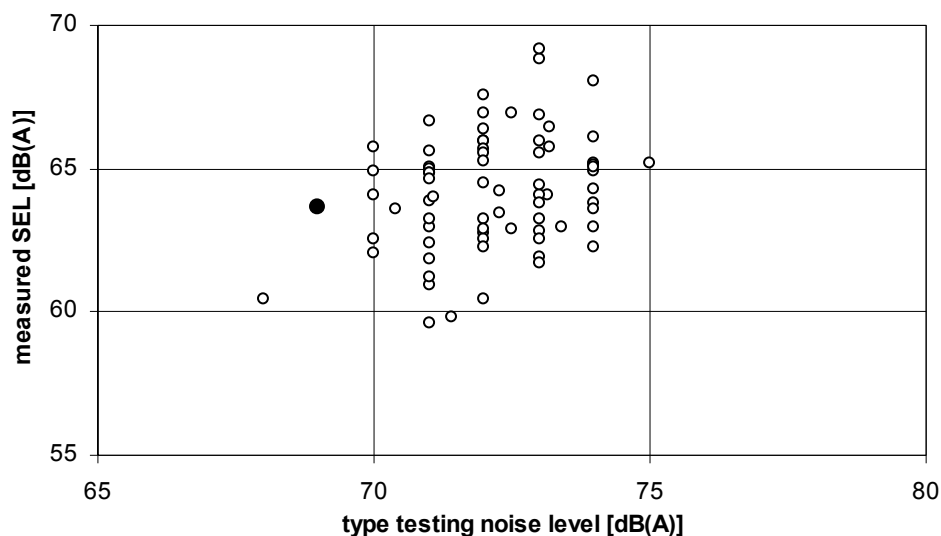


Figure 7: Measured SEL (40-60 km/h, normalized to 50 km/h) compared to registered type test results ($L_{\max}$, full throttle in low gear). The black dot refers to a Toyota Prius.

3.4.2 Reactions on the internet

In discussion forums, blogs and news sites on the internet various remarkable (new) phenomena are discussed. If people were frightened by a near-accident or if they witnessed a real accident with too silent cars, some of them would probably share their experience on the internet. We carried out an internet search using several Dutch keywords in November 2009. This exercise yielded several hits on this topic, but none of them was related to a specific accident in the Netherlands. The discussions did not mention any traceable accidents (date, time, cause) except for one specific accident in the United States: an 8-year old bicyclist was hit by hybrid car that he did not notice because it was too silent. This happened in Minneapolis in May 2008 and was a news item at CNN. The boy, who did not give way to the car, had ‘only minor bumps and bruises’. Because this accident became world news, also Dutch internet users uttered their concerns about the safety of children.

It should be remarked here that the fact that bicycles are much more common in the Netherlands compared to other countries, might have led to a situation where road users are more aware of inaudible vehicles, like bicycles, than elsewhere. Road users, including pedestrians, in the Netherlands also know

that bicyclists can approach from unexpected (illegal) directions. The danger of silent hybrids is therefore probably less than in countries where bicyclists are less dominant and reckless in urban traffic.

3.4.3 Prediction of response time

A lower noise emission means that pedestrians and bicyclists will perceive cars outside their field of vision later. As the time between auditory perception and avoiding possible contact will be reduced, there is less time for anticipating. In order to get an indication of the influence of the absence of engine noise, we have calculated the reaction time for speeds between 15 and 40 km/h. If we assume a background noise of 60 dB to be normal in urban situations, the reaction time for conventional passenger cars will be 1.6 s at 15 km/h. In absence of engine noise, with only tyre-road noise remaining, the response time is halved to 0.7 s. At 25 km/h the respective values are 1.4 s versus 0.9 s, while at 40 km/h 1.4 s and 1.2 s is found. Obviously, the difference vanishes with higher speeds. These results can be compared with those of the Japanese field tests [23]. Though the Japanese did not measure the response time directly but evaluated the distance at which a car approaching from behind was heard, we calculated the response time from distance and speed. These figures are quite similar to the values given above. Below 25 km/h there is considerably less response time in absence of engine noise. From this, a higher incidence rate seems plausible in some situations, such as parking lots and 30 km/h zones.

3.5 Discussion

Organizations of the blind and visually-impaired fear more accidents with hybrid and electric cars because these cars are so silent at low speeds. In America, statistical evidence shows that their concerns are to be taken serious. Though the results of that statistical investigation can be argued, it is obvious that attention should be pay to the potential risks.

The American and Japanese authorities propose to protect the blind and visually-impaired by demanding minimum noise limits or continuous warning sounds for cars. If the Economic Commission for Europe (ECE) will adopt such measures, the future soundscape at crossings, parking lots, and 30 km/h low speed zones will probably then be dominated by artificial sounds. This will affect the potential reduction of noise annoyance determined in Chapter 2, and thereby the reduction of adverse health effects that are caused by noise annoyance [30].

The Japanese proposal to use warning sounds that are less loud and, at the same time, equally noticeable as engine noise does unfortunately not imply that these sounds evoke less annoyance than engine noise. This is because the spectral or temporal properties that makes a relatively silent warning sound sufficiently noticeable might also make it annoying.

The number of accidents with hybrids in the Netherlands is still too low to find significant results, even though the market share of hybrids is the highest one in Europe. The few records of accidents between hybrids and pedestrians or bicyclists that are available do not clarify if the absence of engine noise played a particular role. This topic requires further investigation. Also the behavior of the hybrid car drivers should be studied in situations where other road users may not notice their approach. The discussion so far seems to exclude this behavior, while it is obvious that hybrid drivers are aware of the fact that their car is more silent than other cars. It should therefore be investigated to what extent hybrid drivers adjust their behavior and drive more carefully when their car is operating in electric mode.

4 Conclusion

Electric cars are more silent than cars with an internal combustion engine:

- Hybrid and electric cars are very silent at speeds below 20 km/h. At higher speeds, the difference in noise emission with conventional cars vanishes rapidly. This is because tyre-road noise is the dominant noise source at speeds above 30 km/h.
- In earlier research we showed that a fleet of exclusively hybrid cars leads to a noise reduction of 1 to 3 dB in urban traffic. The number of annoyed urban residents is reduced by one fifth.
- If fully electric cars are regarded, the prospects are even better. A fully electric car fleet would reduce urban traffic noise by 3 to 4 dB. This corresponds to a reduction of the number of annoyed by one third, compared to the present situation.
- These advantages of hybrid or electric cars will only take effect if a substantial part of the current fleet is replaced. It is demonstrated that a transition to a fully hybrid and/or electric car fleet will probably not take place before 2030.

The silent nature of hybrids and electric cars may affect traffic safety:

- At a speed of 15 km/h, the absence of engine noise under circumstances with normal urban background will halve the response time between audible perception and the contact that is to be avoided.
- Because pedestrians and bicyclists partly rely on auditory cues, the approach of silent vehicles may not be noticed in time, especially when these vehicles are out of eye-range. Such situations may occur in parking lots and 30 km/h zones and also at crossings or exits.
- Up to now, no statistical evidence is found in the Netherlands and in Japan for a higher incidence rate for hybrid cars and pedestrian or bicyclists. In the United States, however, a significant relationship has been found. In situations where cars drive slowly (slowing down, stopping, backing up, parking manoeuvres) hybrid cars were involved twice as much compared to conventional cars. Though the meaning of that statistical investigation can be argued, it is obvious that attention should be paid to the potential risks.
- American and Japanese authorities are seeking for measures to protect other road users, in particular the blind and visually-impaired, against the potentially higher risks of cars that are too quiet. They propose to specify minimum noise levels for motor vehicles, which implies that cars must produce artificial sounds whenever their engine is too silent.
- If the Economic Commission for Europe (ECE) will adopt such minimum noise levels, the future soundscape at crossings, parking lots, and 30 km/h zones in Europe may be dominated by artificial sounds. This will affect the potential reduction of noise annoyance found in this study and thereby the reduction of adverse health effects that are caused by noise annoyance. In this respect, it is recommended to investigate other safety measures than minimum noise levels or continuous warning sounds.

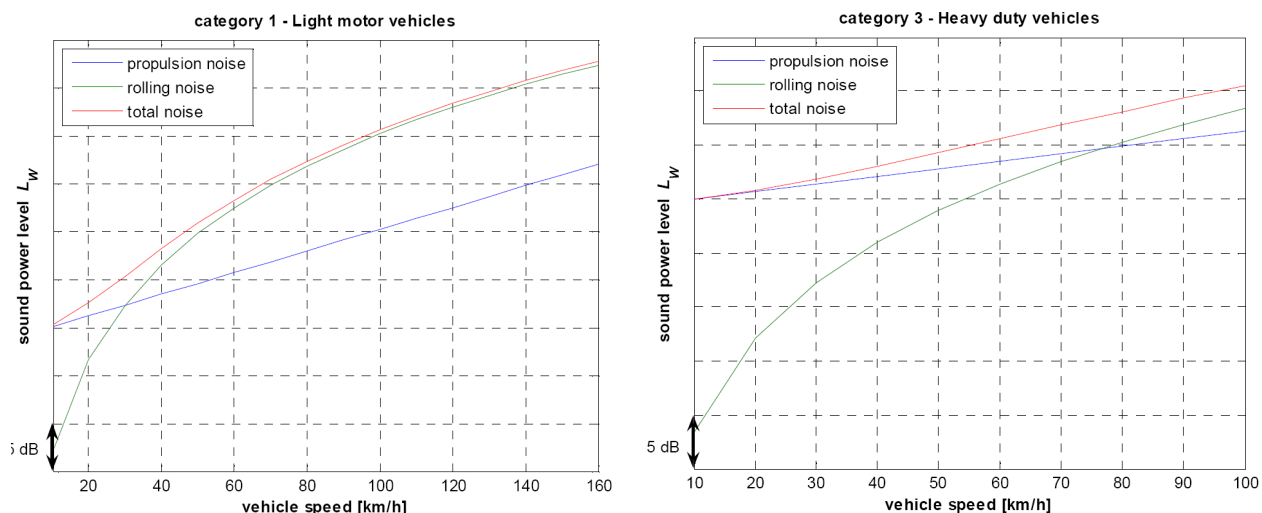
References

- [1] *Invloed hybride voertuigen op de geluidbelasting*, RIVM Report 680300006/2008, E. Verheijen, December 2008.
- [2] <http://www.automotive-online.nl/upload/feitencijfers/1256828802Hybridestatistiek.pdf>, visited December 2009.
- [3] 'Hybrids in Japan Grabbed 12% New Vehicle Market Share in May', published May 2009, <http://www.greencarcongress.com/2009/06/japan-may-20090606.html>
- [4] *Aantal hybride personenauto's verdubbeld*, CBS Webmagazine, published 22 June 2009. <http://www.cbs.nl/nl-NL/menu/themas/verkeer-vervoer/publicaties/artikelen/archief/2009/2009-2813-wm.htm>
- [5] *Milieuverslag 2005*, Stichting Auto Recycling Netherlands, published 2006.
- [6] *Elektrisch autorijden – Evaluatie van transitities op basis van systeemopties*, Netherlands Environmental Assessment Agency (PBL), report 500083010, D. Nagelhout, J.P.M. Ros, January 2009.
- [7] *Actieplan Elektrisch Rijden - Op weg naar één miljoen elektrische auto's in 2020*, Background document, The Netherlands Society for Nature and Environment, March 2009.
- [8] Gijsjan van Blokland en Bert Peeters, Modeling the noise emission of road vehicles and results of recent experiments, paper 895 of Internoise 2009, Ottawa, August 2009
- [9] *Modelling of Environmental Noise at RIVM*, E. Schreurs, J. Jabben and E. Verheijen, RIVM Report 680740003/2009, to be published in January 2010.
- [10] *Elements for a position paper on relationships between transportation noise and annoyance*, H.M.E. Miedema and C.G.M. Oudshoorn, TNO Report PG/VGZ/00.052, 2000. Percentages of annoyed per noise class, based on these relationships, are laid down in the Dutch regulation *Regeling Omgevingslawaaai* (2004). http://www.st-ab.nl/wettennr05/0502-021_Regeling_omgevingslawaaai.htm
- [11] *Ex antetoets Startnotitie Randstad 2040*, Ries van der Wouden (RPB), Rienk Kuiper (MNP), Carel Eijgenraam (CPB), 2008.
- [12] 'Japan rethinks silent hybrid cars', <http://news.bbc.co.uk/2/hi/asia-pacific/8132548.stm>, published July 2009
- [13] 'Hybrid Cars Are Harder to Hear', Riverside Univeriteit van California, http://newsroom.ucr.edu/news_item.html?action=page&id=1803, published April 2008,
- [14] 'Young Inventors Make Hybrid Cars Noisier', Stanford Graduate School of business, http://www.gsb.stanford.edu/news/headlines/hybrid_7_08.html, Enhanced Vehicle Acoustics Inc., published July 2008
- [15] 'Lotus designs noise-warning systems for hybrid cars', <http://blogs.automobilemag.com/6278477/green/lotus-designs-noise-warning-systems-for-hybrid-cars/index.html>, published August 2008
- [16] 'Leise Hybrid-Autos gefährden Blinde', <http://presstext.de/news/080223001/leise-hybrid-autos-gefaehrden-blinde/>, published February 2008
- [17] 'Ophef over hybride auto's', Viziris, <http://www.viziris.nl/actualiteit/nieuws/ophef-over-hybride-autos.html>, published October 2007
- [18] 'NHTSA to Hear 'Silent Killer' Complaints', http://www.consumeraffairs.com/news04/2008/06/prius_nhtsa.html, published June 2008
- [19] 'Blind advocates lobby for noisier hybrid cars', http://news.cnet.com/8301-10784_3-9874568-7.html, February 2009

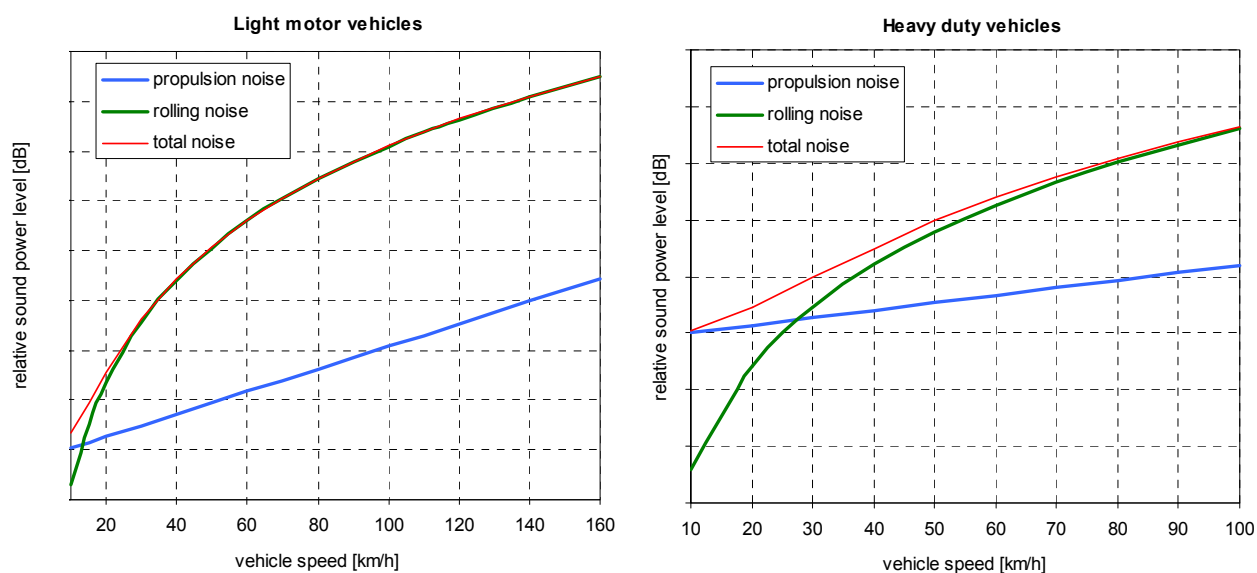
- [20] ‘U.S. Representatives Edolphus Towns and Cliff Stearns Introduce Pedestrian Safety Enhancement Act’, <http://www.reuters.com/article/pressRelease/idUS192328+28-Jan-2009+BW20090128>, published January 2009
- [21] *Incidence of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles*, NHTSA Technical Report DOT HS 811 204, <http://www-nrd.nhtsa.dot.gov/Pubs/811204.PDF>, September 2009
- [22] ‘Hybrids: Is a Little of the Green Rubbing Off? Quality Planning’, <http://www.qualityplanning.com/index.cfm?event=showNews&newsId=46&displayType=page>, Juli 2009
- [23] A Study on Approach Warning Systems for hybrid vehicle in motor mode JASIC, Japan, <http://www.unece.org/trans/doc/2009/wp29grb/ECE-TRANS-WP29-GRB-49-inf10e.pdf>, February 2009
- [24] A Study on Approach Audible System for Hybrid Vehicles and Electric vehicles, Second Report, JASIC, Japan, <http://www.unece.org/trans/doc/2009/wp29grb/ECE-TRANS-WP29-GRB-50-inf08e.pdf>, September 2009
- [25] Private communication between Edwin Verheijen (RIVM) and Chris Schoon (SWOV), April 28th, 2009
- [26] Accident data provided by RWS (Data-ICT-Dienst) to RIVM, traffic accidents 2008, August 31st, 2009
- [27] ‘VCA car fuel database’, <http://www.vcacarfueldata.org.uk/downloads/>, visited June 2009
- [28] *Noise Monitor 2008*, RIVM report 680740002/2009, Eric Schreurs, Edwin Verheijen, Charlos Potma and Jan Jabben, September 2009.
- [29] ‘8-year old boy hit by Toyota Prius, raises debate over hybrid minimum sound levels’, <http://www.leftlanenews.com/8-year-old-boy-hit-by-toyota-prius-raises-debate-over-hybrid-minimum-sound-levels.html>, May 2008
- [30] *Trends in the environmental burden of disease in the Netherlands, 1980 – 2020*, RIVM report 500029001/2005, Anne Knol and Brigit Staatsen, 2005. <http://www.rivm.nl/bibliotheek/rapporten/500029001.html>

Appendix 1 Engine noise and tyre-road noise

The relative contribution of propulsion noise and tyre-road noise is depicted below, for light motor vehicles and heavy duty trucks with internal combustion engines. We have copied these figures from reference [8].



In order to make a prediction of the noise levels for the case of fully electric vehicles, we assume that the electric motor is 10 dB more silent than a combustion engine. The rolling noise is the same. By combining the rolling noise and electric motor noise, we were able to compose the graphs shown below.



Eventually, by subtracting the total noise for electric cars (below) from that by conventional cars (above), the noise reduction of fully electric cars is estimated, shown in Figure 3 of Section 2.1.

Appendix 2 Input for urban noise calculation

The noise reduction of a fleet of fully electric cars in urban traffic is calculated for different traffic flow types. These traffic flow types can occur on different roads on different moments of the day. The noise reduction for each flow type is derived from the graphs of Appendix 1. The noise reductions are given in Table B2.1 for 25, 40 and 50 km/h. For heavy duty traffic, a fleet composition of 20% diesel engines and 80% electric engines is assumed. For medium trucks, the same reductions as for light motor vehicles are used.

Table B2.1 Noise emission reductions [dB(A)] for an electric fleet in different urban traffic flow conditions.

Flow type	reference speed	Light	Medium	Heavy
'Urban, normal'	25	-5	-5	-6
'Urban, fluent flow'	40	-2	-2	-4
'Basic 50 km/h'	50	-1	-1	-3

Next, these flow types are attributed to the so-called BASNET road categories that are used in our calculation model, see Table B2.2.

Table B2.1 Relationship between BASNET road categories and urban traffic flow types.

BASNET category	Day (7am–7pm)	Evening (7pm–11pm)	Night (11pm–7am)
Type 1 & 3 (4 lanes)	'Urban, fluent flow'	'Urban, fluent flow'	'Basic 50 km/h'
Type 5 & 7 (2 lanes)	'Urban, normal'	'Urban, normal'	'Basic 50 km/h'
Type 9 & 11 (residential)	'Urban, normal'	'Urban, normal'	'Urban, fluent flow'

Remarks:

- Some type 1 & 3 roads have a speed limit of 70 km/h. Therefore the average traffic speed is slightly higher than on other road types.
- Type 9 & 11 roads usually have many side roads, bends and they contain parked cars. Though traffic congestion is not a problem on these roads, the speed is often low, even at night.
- The traffic speed in the day period must be regarded as an average. During rush hours the speed will be less, during 10am-3pm the speed will be higher.
- Roads with pavers are not distinguished in the calculation model. Because there is probably no acoustic advantage of electric cars on such road surfaces, the model will overestimate the noise reduction on such roads.

Combining Table B2.1 with Table B2.2 yields Table B2.3.

Table B2.3 Electric fleet noise correction [dB] per vehicle type, period and road category.

reduction (dB)	Type 1 & 3	Type 5 & 7	Type 9 & 11
Light day	-2	-5	-5
Light evening	-2	-5	-5
Light night	-1	-1	-2
Medium day	-2	-5	-5
Medium evening	-2	-5	-5
Medium night	-1	-1	-2
Heavy day	-4	-6	-6
Heavy evening	-4	-6	-6
Heavy night	-3	-3	-4

Junction correction

According to the Dutch calculation model, near road junctions there is noise emission penalty of maximum 2.4 dB. This penalty represents the excess noise due to braking and accelerating, and is only taken into account for trucks. The correction is smaller than 2.4 dB if the traffic intensity of the branches of a junction differs to a certain extent. For an electric fleet, we assume a noise *reduction* at junctions of maximally 1 dB.

Appendix 3 Results noise calculation

Table B3.1 Number of dwellings per noise class in the town of Utrecht.

Noise class	Present car fleet		Hybrid car fleet		Electric car fleet	
	#	percentage*	#	percentage	#	percentage
<=54 dB	53600	48%	62300	56%	67000	60%
55 – 59 dB	19700	18%	20500	18%	22400	20%
60 – 64 dB	22300	20%	21000	19%	18300	16%
65 – 69 dB	15100	13%	8100	7%	4400	4%
70 – 74 dB	1500	1%	300	0%	100	0%
>=75 dB	0	0%	0	0%	0	0%

* Percentage with respect to the total number of 112,200 dwellings in this area.

Table B3.2 Annoyance due to traffic noise in Utrecht (260,000 inhabitants in this area).

Noise class	Annoyed				Severely annoyed			
	perc.*	present	hybrid	electric	perc.*	present	hybrid	electric
55 – 59 dB	21	9500	9900	10800	8	3600	3800	4100
60 – 64 dB	30	15400	14500	12600	13	6700	6300	5500
65 – 69 dB	41	14300	7600	4200	20	7000	3700	2000
70 – 74 dB	54	1900	300	100	30	1000	200	100
>=75 dB	61	0	0	0	37	0	0	0

* Percentage of annoyed calculated with dose-effect relationships [10].

Appendix 4 Traffic accidents

In 230 out of 140,000 accidents with cars in 2008 (0,2 %) an electric or hybrid car was involved [26]. Only in seventeen of these 230 cases the accident was between a pedestrian or bicyclist and an electric or hybrid car. In each of these cases the car was a Toyota Prius, which was until 2008 the dominant hybrid car type in the Netherlands. Copies of the seventeen police reports, made available to RIVM by RWS Data-ICT-Dienst, were studied to find a clue about whether the car was too silent to be noticed in time by the pedestrian or bicyclist.

The table below summarizes the circumstances of the seventeen accidents. It must be noted that two reporting formats are used by the police, of which only one offers us a short description of the circumstances that lead to the crash. Therefore, for only ten accidents we were able to judge if the car driver or the pedestrian/bicyclist was the offender. The other seven cases, marked in the right-hand column with a question mark, are undecided.

None of the ten descriptions mentioned explicitly that the car was inaudible. Also other clues about the audibility of the car, such as speed, were absent. In some cases there was a crossing involved, but in those cases the crash did not seem to happen just at the crossing. The reporting style used by the policemen is rather brief, which probably means that even if the pedestrian or bicyclist would make a remark about the silent nature of the car, it is doubtful whether this would be reported.

It is concluded therefore that there is no evidence that the absence of engine noise played a role in these cases.

Built-up area	Speed limit [km/h]	Type of crash	Result	Wrong*
Y	30	Frontal, bike + car	injury/damage	?
Y	30	Lateral, fiets + auto	damage	Bicyclist
Y	30	Lateral, fiets + auto	damage	Hybrid car
Y	50	Frontal, bike + car	damage	?
Y	50	Lateral, bike + car	injury/damage	Hybrid car
Y	50	Frontal, bike + car	injury/damage	?
Y	50	Lateral, bike + car	injury/damage	?
Y	50	Crash bike + car	injury/damage	?
Y	50	Lateral, bike + car	injury/damage	Bicyclist
Y	50	Front/rear, bike + car	injury/damage	Bicyclist
Y	50	pedestrian + car	injury/damage	Pedestrian
Y	50	Lateral, fiets + auto	damage	?
Y	50	pedestrian + car	damage	?
Y	50	Lateral, bike + car	injury/damage	Hybrid car
Y	50	Lateral, bike + car	damage	Bicyclist
Y	50	Lateral, bike + car	injury/damage	Hybrid car
N	80	pedestrian + car	injury/damage	Hybrid car

* 'Wrong' indicates the road user that failed to give way.

RIVM

National Institute
for Public Health
and the Environment

P.O. Box 1
3720 BA Bilthoven
The Netherlands
www.rivm.com