The impact and cost effectiveness of Dutch air quality policies

Committed to the Environment

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Introduction

Over the past ten to fifteen years the Dutch government has implemented a range of policies to improve the country's air quality, on top of policy initiated at the European level. With its project 'National part of joint air quality audit' the Netherlands Court of Audit seeks to gain insight into the (cost) effectiveness of Dutch air quality policies impinging on the road traffic sector. To this end the Court commissioned CE Delft to calculate the impact and cost-effectiveness of eight policies with respect to NO_x (nitrogen oxide) and $PM_{2.5}$ (fine particulate) emissions reduction.

Impacts on NO_x and $PM_{2.5}$

The eight policied investigated are listed in Table 1. Between 2006 and 2015 there was a major decrease in road traffic NO_x and $PM_{2.5}$ emissions, due mainly to EU source policy, i.e. European exhaust standards for passenger car and HGV engines. Road traffic $PM_{2.5}$ emissions were more than halved during this period, while NO_x emissions were 40% lower in 2015 than 2006. Compared with a scenario without the eight policies, from 2006 through to 2015 the policies together led to a 2% annual decrease in road traffic emissions of both NO_x and $PM_{2.5}$ after correction for free-riders[1].

Table 1 - Costs, duration and impacts of the eight policies investigated, with abbreviated names in brackets

Policy	Subsidy duration	Number of vehicles	Total costs of subsidy scheme (€)	Cumulative impact on NO_x (mln. kg)*	Cumulative impact on $PM_{2.5}$ (mln. kg)*
National scrappage scheme for cars and vans (Scrappage)	2009-2010	83,444	€ 85,120,000	- 0.70**	- 0.01
Subsidy scheme for new Euro V/EEV HGVs and buses (Euro V)	2006-2011	34,260	€ 53,220,000	- 17.25	+0.04
Subsidy scheme for Euro VI HGVs and buses (Euro VI)	2012-2013	6,116	€ 28,150,000	- 3.6	- 0.02
Subsidy scheme for new diesel taxis and vans with particle filter (STV)	2006-2010	78,428	€ 35,250,000	-	- 0.48
Subsidy scheme for retrofitted particle filters in cars and light vans (SRL)	2006-2010	79,971	€ 39,780,000	-	- 0.13
Subsidy scheme for retrofitted particle filters in HGVs and buses (SRH)	2006-2010	26,986	€ 151,820,000	-	-0.48
Subsidy scheme for new low-emission taxis and vans (LETV)	2012-2015	2,408	€ 6,450,000	- 0.16	<+ 0.00
Purchase Tax discount for Euro 6 diesel cars (Euro 6 discount)	2011-2013	13,647	€ 8,080,000	- 0.55	< - 0.00

* The cumulative effect over the years the measure reduced emissions has been corrected for free-riders.

** In 2010 a total of 107 mln. kg NO_x and 4.0 mln. kg $PM_{2.5}$ was emitted by road traffic.

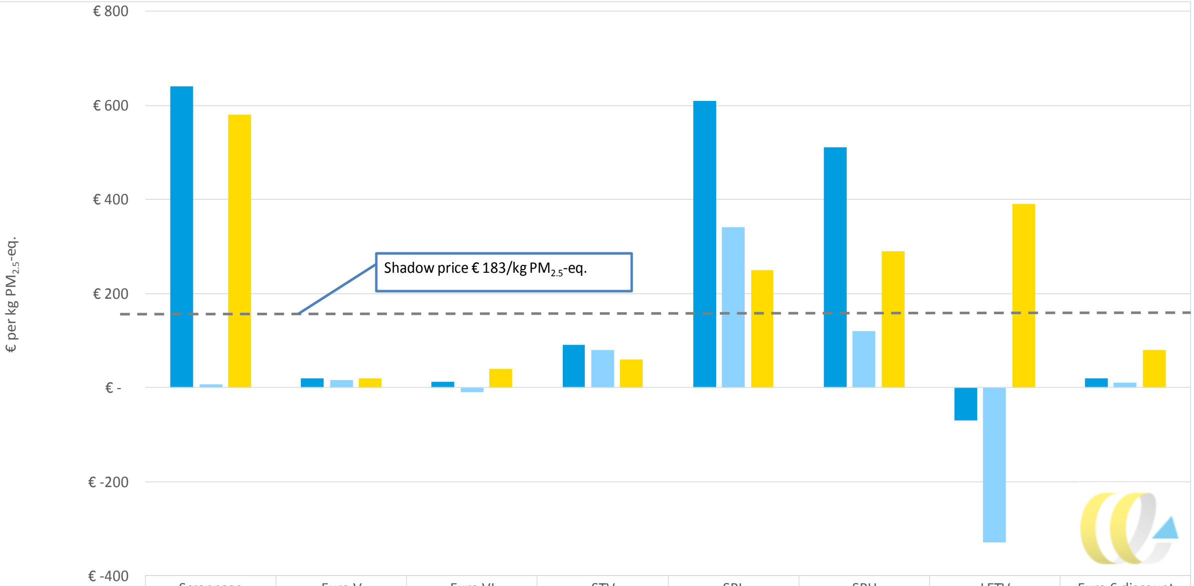
[1] Free-riders are investors in environment-friendly technologies who would have invested at the same time even without a subsidy scheme. The higher the percentage of free-riders, the lower the cost-effectiveness of the subsidy scheme. The precise magnitude of the free-rider effect is hard to establish and is fraught with uncertainty.

Cost-effectiveness

The costs and cost-effectiveness of the eight policies were calculated from three different perspectives: end-user, government and national[2]. The national cost-effectiveness is a measure of the policy's efficacy: was it worth society investing in? The end-user and government perspectives indicate what share of the costs is borne by whom.

Figure 1 compares the cost-effectiveness of the eight policies according to these three perspectives, expressed in $PM_{2.5}$-equivalents[3].

Figure 1 - Cost-effectiveness of the eight air quality policies, corrected for free-riders



	Scrappage	Euro V	Euro VI	STV	SRL	SRH	LETV	Euro 6 discount
National costs	€ 640	€ 20	€ 12	€ 90	€ 610	€ 510	€ -70	€ 20
End-user costs	€ 6	€ 16	€ -10	€ 80	€ 340	€ 120	€ -330	€ 10
Government costs	€ 580	€ 20	€ 40	€ 60	€ 250	€ 290	€ 390	€ 80

The national cost-effectiveness of the policies Euro V, Euro VI, STV, LETV and Euro 6 discount is negative, being lower than the average damage costs of € 183 per kg $PM_{2.5}$-eq. From the perspective of society as a whole, these are all policies whose benefits outweighed the costs. From the national perspective the SRL, scrappage and SRH schemes were the least cost-effective. At first sight these policies seem expensive, but because some of them impact mainly on urban traffic (scrappage, SRP and to a lesser degree SRH) and can help resolve local air quality hotspots in cities where European air quality limits are exceeded, their cost-effectiveness should be viewed in that light and compared with the available alternatives.

In the case of low-emission taxis and passenger cars, there are major benefits for the end-user, but the risks associated with the vehicle's uncertain residual value or the as yet still limited charging and CNG-filling infrastructure needs to be included in an overall evalution of this policy. For various other schemes, including the scrappage scheme, the bulk of the costs are borne by government, to limit end-user costs and thus incentivize the scheme.

[2] The national perspective includes only costs, not transfers like taxes and subsidies.

[3] To compare the different policies the damage due to NO_x has been expressed relative to fine particulates, in terms of $PM_{2.5}$-equivalents, with 1 kg NO_x approximately 0.19 times as damaging as 1 kg $PM_{2.5}$. For a further explanation see Section 2.3.

If a policy is designed to encourage uptake of a new technology, it is scarcely feasible to estimate its effectiveness **a priori**. Only when the new vehicles have been on the road for a while and emissions have been sufficiently monitored under real-world conditions can conclusions be drawn as to the NO_x and/or $PM_{2.5}$ emissions reductions achieved. This was mainly relevant for the subsidies on Euro 6 diesel vehicles, Euro V HGVs and the SRL and SRH schemes, where the vehicles proved to be dirtier in practice than estimated beforehand. Nonetheless, it is generally to be recommended to undertake prior assessment of how effective specific technologies are and to carry out extensive trials on this issue. In addition, other criteria besides cost-effectiveness should also be taken into account, such as local air quality hotpots in towns and cities, where only a limited number of policies are effective.

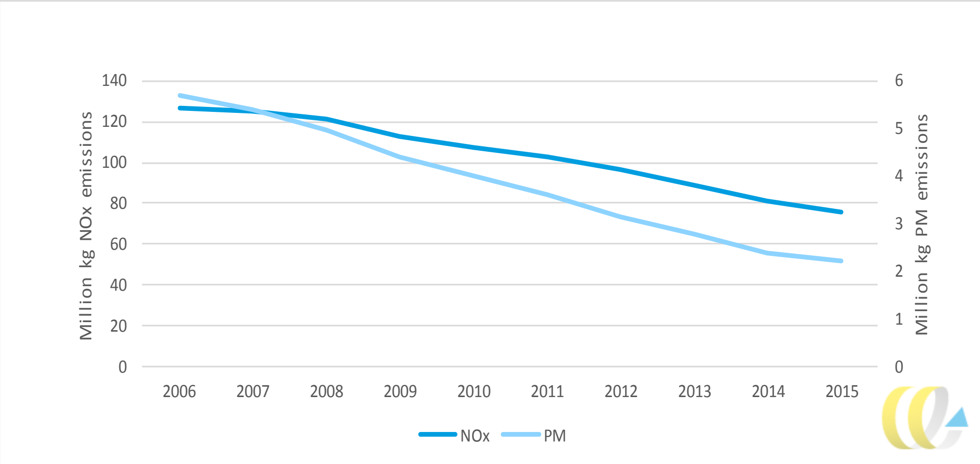
1 Introduction

1.1 Background

As a result of European vehicle emission standards, Dutch road traffic emissions have declined considerably in recent years. These 'Euro standards'[4], which have been periodically tightened since about 1990, have moved car-manufacturers to implement technologies to reduce emissions of, **inter alia**, NO_x (nitrogen oxides) and $PM_{2.5}$ (fine particulates). These technologies include three-way catalytic converters and particulate filters. Epidemiological studies have shown a statistical correlation between a range of health disorders and exposure to $PM_{2.5}$ and nitrogen dioxide (PBL, 2016)
An extensive recent study also found a statistically significant correlation between long-term exposure to $PM_{2.5}$ and nitrogen dioxide and various kinds of premature mortality in the (Fischer, et al., 2015).

Over the past ten to fifteen years the Dutch government has made considerable efforts to improve air quality in our country, with intense cooperation among government agencies at the national, provincial and municipal level under the terms of the National Air Quality Cooperation Programme (NSL) and within other frameworks. These policy efforts were directed largely towards the traffic sector because of its major impact on local air quality. Figure 2 shows trend in road traffic emissions from 2006 to 2015. As can be seen, there was a major decline in emissions of both NO_x and particulates during this period, in the latter case to a greater extent. The present study sets out the extent to which these emission cuts can be traced back to government policies.

Figure 2 - Trends in NO_x and particulate emissions between 2006 and 2015



[4] For more information see www.dieselnet.com.

With its project 'National part of joint air quality audit' the Netherlands Court of Audit seeks to gain insight into the efficacy and cost-effectiveness of Dutch air quality policy to date. As part of this effort the Court commissioned an exploratory study on the cost-effectiveness of a number of traffic policies, viz. policy policies implemented over the last ten to fifteen years and aimed specifically at improving air quality. The Court of Audit asked CE Delft to assess the effectiveness of eight policies in terms of NO_x (nitrogen oxide) and $PM_{2.5}$ (fine particulate) emissions reductions as well as their cost-effectiveness.

In the project 'National part of joint air quality audit' the Netherlands Court of Audit is collaborating with the Netherlands Environmental Assessment Agency (PBL) and the National Institute for Public Health and the Environment (RIVM). RIVM will use CE Delft's emission - calculations to estimate changes in NO_x and particulate concentrations. RIVM has also been asked to estimate the public health benefits accruing from the eight policies. PBL is supervising the project and contributing expertise on vehicle emissions, policy impacts and costs.

1.2 Aim and scope of this study

The aim of this study is to assess and compare the efficicacy and cost-effectiveness of eight air quality policies directed towards road traffic. To this end the following questions were answered:
1. What reductions in particulate ($PM_{2.5}$) and nitrogen oxide (NO_x) emissions have been achieved thanks to the policies?
2. What did the policies cost per kilogram avoided $PM_{2.5}$ and NO_x emission from various cost perspectives?
3. How does the cost-effectiveness of the various policies compare and how are any differences to be explained?

For each policy, all impacts on emissions were calculated per annum. This means the resultant emission cuts are known annually from 2006 onwards up to the time a policy-affected vehicle leaves the vehicle fleet (due to scrappage or export). Not all these data are to be found in this report, however. For more detailed results CE Delft and the Netherlands Court of Audit should be consulted.

Together with the Court of Audit and PBL a list of eight air quality policies was drawn up that have impinged on road vehicles in recent years. These policies and their abbreviated name are shown in Table 2 along with the period they were in force. In Chapter 3 each policy is described in more detail.

Table 2 - Policies examined

	Policy	Duration
1	National scrappage scheme for cars and vans (Scrappage)	2009-2010
2	Subsidy scheme new Euro V/EEV HGVs and buses (Euro V)	2006-2009
3	Subsidy scheme for Euro VI HGVs and buses (Euro VI)	2012-2013
4	Subsidy scheme for new diesel taxis and vans with particulate filter (STV)	2006-2010
5	Subsidy scheme for retrofitted particulate filters in cars and light vans (SRL)	2006-2010
6	Subsidy scheme for retrofitted particulate filters in HGVs and buses (SRH)	2006-2010
7	Subsidy scheme new low-emission taxis and vans (LETV)	2012-2015
8	Purchase Tax discount for Euro 6 diesel cars	2011-2013

The cost-effectiveness (in €/kg $PM_{2.5}$ and €/kg NO_x) of the various policies was calculated from three cost-perspectives:

- Government costs: this perspective includes only costs incurred by national government. These include administrative costs, subsidy payments and changes in tax revenues (e.g. extra fuel-duty revenues if a policy leads to higher vehicle fuel consumption).
- National costs, calculated using the Netherlands' standard 'Environmental Cost Method' (VROM, 1998) : these are all the direct costs and benefits of the policies from the perspective of Dutch society as a whole. These do not include transfers such as taxes and subsidies because these remain available to society.
- End-user costs: these are all the direct costs and benefits for vehicle owners, including taxes and subsidies.

National costs represent a policy's cost efficiency: how do the costs of the underlying technology[5] compare to the emission cuts achieved? These costs may be shared by end-users and the government, as represented in the cost perspectives concerned.

Chapter 2 provides a further description of the procedures followed to calculate emissions cuts and cost-effectiveness. Chapter 3 describes how each policy works, how the calculations were performed and what the results are. In Chapter 4, finally, the various policies are compared.

[5] The aim of a subsidy is to induce people to purchase a different vehicle with a different technology. The subsidy thus promotes a technology.

2 Procedure/methodology

2.1 Introduction

In this chapter we describe the general methodology employed for calculating emissions and cost-effectiveness, which is similar across all eight policies. In Section 2.2 we first consider how impacts on emissions were determined, then in Section 2.3 how costs were calculated. In Chapter 3**Fout! Verwijzingsbron niet gevonden.** we examine each individual policy and consider the calculation procedure in more detail.

2.2 Emission calculation procedure

To calculate the emissions cuts due to the policies a ten-step procedure was adopted:
1. Establish the number of vehicles affected by the policy.
2. For each vehicle type affected by the policy, define a reference vehicle.
3. Determine the difference in emission per kilometre between the reference vehicle and the vehicle for which the policy was in force (the 'policy vehicle').
4. Multiply the difference in emission per vehicle-kilometre (Step 3) by the number of vehicles (Step 1) to obtain the total emission reduction per kilometre for each vehicle category.
5. For each vehicle category, establish how many years the policy had an impact.
6. For each vehicle and year of manufacture, determine the average annual mileage on Dutch roads during the period in which the policy had an impact.
7. Allocate mileages across road types, viz. urban, rural and motorway.
8. Multiply annual average mileage by emission cuts per kilometer to obtain annual emission cuts per vehicle category.
9. Sum the various emission cuts per vehicle category to obtain total annual emission cuts.
10. Sum the emission cuts in the various impact years to obtain the cumulative impact of the policy.

These ten steps yield the cumulative impact on NO_x and $PM_{2.5}$ emissions of the policy from the moment a vehicle is bought (or retrofitted) due to the policy through to the time it leaves the vehicle fleet (through export or scrappage). This period is thus longer than the time the policy was in force because vehicles continue to drive on Dutch roads after the policy is discontinued, so the policy still reduces emissions.

We now provide a more detailed explanation of the ten steps, describing the main assumptions and the data sources used.

2.2.1 Calculate number of vehicles (Step 1)

To calculate the emission cuts achieved under a given policy, it must first be established precisely what types of vehicle were subsidized. This is important because emissions may vary widely according to vehicle type. Passenger cars generally have lower NO_x and $PM_{2.5}$ emissions than vans and HGVs. At the same time European emissions standards (the 'Euro standards') mean older vehicles have higher emissions than newer vehicles, while these standards differ per vehicle category, moreover.

The emissions of each type of vehicle per kilometre are established annually by the Taskforce on Transportation (part of the Dutch Pollutant Release and Transfer Register) and are well-documented in CBS; PBL ; TNO; RWS,(2017). These so-called emission factors are given for three road types: urban (built-up areas), rural and motorway.

The eight policies as a whole relate to the following vehicle categories:
- passenger cars;
- vans (light-duty, heavy-duty);
- taxis;
- HGVs (light-duty, mid-range, heavy-duty);
- tractor units[6];
- buses.

For certain policies it is well known from review studies and progress reports how many subsidy applications were honoured per vehicle category. In other cases this is less accurately known. In the latter cases we examined the number of comparable vehicles in the overall vehicle fleet (and the associated ratios among vehicles), taking CBS; PBL ; TNO; RWS, (2017) as our source.

For certain policies the number of subsidized vehicles was known, but the figures were reported according to engine capacity class. For these vehicles these data therefore first had to be converted to the vehicle types distinguished by CBS; PBL ; TNO; RWS, (2017). For this purpose use was made of TNO, (2013) a review of the average weight and engine volume of vehicle categories used in the Netherlands.

In cases where the number of subsidies granted was unknown, the numbers of vehicles involved was estimated on the basis of total subsidy outlay, new vehicle sales and subsidy per vehicle category. In the discussion of how each policy plays out in Chapter 3 we consider in more detail how the number of vehicles was established for each individual measure.

2.2.2 Reference vehicle (Steps 2, 3 and 4)

Each of the eight policies examined incentivized uptake of cleaner types of vehicle. This uptake meant the share of 'dirty' vehicles was lower than would have been the case without the various policies. The resultant emissions reduction is given by the difference in emissions between the **policy vehicle** and the **reference vehicle**. In the case of the Euro V subsidy, for example, parties intending to buy a new heavy-duty vehicle were eligible for a subsidy if they purchased a Euro V rather than Euro IV vehicle. In this case the former is the 'policy vehicle', the latter the 'reference vehicle'. The environmental gain is then measured as the difference in emissions between the two.

The real-world emissions[7] of the various vehicles per road-kilometre are reported in CBS; PBL ; TNO; RWS, (2017). Multiplication of the emission reduction per vehicle per kilometre by the number of vehicles for which a subsidy was granted and the number of kilometres driven (per road type) yields the emission cut per road-kilometre for the various vehicle categories.

2.2.3 Impact duration (Steps 5 and 6)

The environmental gains are secured throughout the time the vehicle is on the road. As the policies are aimed at improving Dutch air quality, the total number of kilometres driven in the Netherlands was assessed[8]. Netherlands Statistics (CBS) reports the average mileage per vehicle category, with a breakdown by vehicle age and year of manufacture. New vehicles have a higher average mileage, as do vehicles manufactured more recently. Data on average scrappage and export ages for the various vehicles were obtained from TNO (2015c). Using these data it can be established how long a vehicle is

[6] Tractor units are heavy-duty HGVs that pull a semi-trailer (not to be confsed with farm tractors).

[7] For the calculations in this study we use only the real-world emission factors established by the Taskforce on Transportation, which in turn obtain their emission factors from TNO. Due allowance has thus been made for differences between type-approval test emissions of NO_X and $PM_{2.5}$ and those in the real world.

[8] Emission cuts occurring when vehicles are on foreign roads are thus not included.

on Dutch roads on average. If it is also known from what vehicle age the policy has an impact (which can sometimes be derived from review studies and progress reports) how long the policy has had an impact on the vehicle can be calculated. As most policies are directed towards new vehicles, it is the scrappage and export age that determines how long a policy is effective. The SRL and SRH policies (see Table 23) incentivized particulate filters retrofitted in existing vehicles. Because these vehicles were already several years old, these policies were effective for fewer years than those directed towards new vehicles.

In calculating the duration of the impact it was assumed that all vehicles making use of the subsidy scheme remain in the fleet for the same length of time. The duration depends on the vehicle category and its service life, as shown in Table 3. However, this approach makes no allowance for the fact that a vehicle may sometimes already leave the fleet after a year or may remain on Dutch roads for far longer than the average service life. This means emission cuts have been probably slightly overestimated in the first few years, with later impacts underestimated. For the **cumulative** emission impacts that are the key focus of the present report this approach has no consequences, however. In establishing the duration of the impact, due allowance should ideally be made for the annual probability of vehicles leaving the fleet sooner or later. In consultation with PBL and the Court of Audit it was examined whether this issue could be factored into the calculations. This proved unfeasible, though, as vehicle statistics permit insufficient distinction between vehicles imported, exported and otherwise leaving the fleet.

2.2.4 Road type (Steps 7 to 10)

Using the data on average mileage and average age before leaving Dutch roads the average mileage driven by a policy vehicle on Dutch roads can be calculated. The average split on the three road types (urban, rural, motorway) is available in CBS; PBL ; TNO; RWS, (2017). A heavy-duty HGV drives relatively more kilometres on motorways than a light-duty HGV, for example, while a new passenger car drives relatively more motorway kilometres than an old vehicle. By multiplying the ratio between road types by mileage the average annual mileage per road type was calculated. Multiplication by the per-kilometre emission reduction for each vehicle category then yields the annual emission reduction per road type per vehicle category. Summation across road types and vehicle categories gives the total annual emission reduction attributable to a given policy. Policies will have the greatest impact in the first few years, as annual mileages decrease with growing vehicle age. The impact in the first year will be lower, though, as most vehicles are purchased in the course of a year and consequently drive fewer kilometres in that year. Summing the emission reductions for the various years and vehicle categories then gives the cumulative emission reduction of the policy in question.

Table 3 reviews the key characteristics of the vehicle categories to which the subsidy schemes applied and used for the calculations in this report. The data are from TNO (2013), TNO (2015b,c) and Statline (2017). For passenger cars, average weight and engine volume are not important for the calculations and are therefore not reported here.

Table 3 - Characteristics of average vehicle categories

Vehicle category	Weight category (kg)	Average weight (kg)	Average engine vol. (kW)	Fuel cons.[9] (l/100 km)	Years in vehicle fleet	Average annual mileage (km)	Annual mileage in NL (km)
Diesel pass. cars	< 3,500	n.a.	n.a.	5.9	9	23,000	21,000
Taxis	< 3,500	2,000	140	8	4	60,000	55,000
Light vans	< 2,000 kg	1,557	50	8.7	11	16,000	15,500
Heavy vans	> 2,000	2,200	80	9.9	11	20,000	19,500
Light HGVs	3,500 < GVW[10] < 10,000	5,210	126	8.9	12	26,500	24,000
Medium HGVs	10,000 < GWV < 20,000	11,400	239	17.8	12	45,000	37,000
Heavy HGVs	GWV > 20,000	19,600	302	24.9	10	53,700	39,000
Tractor units	GWV > 20,000	28,239	290	28.6	7	100,000	55,000
Buses	GWV > 20,000	23,000	239	23.5	9	75,000	65,000

2.2.5 Free-riders

In describing the above steps it was consistently assumed that purchase of a 'policy vehicle' was motivated by the subsidy, with no allowance for the possibility of it being made without the subsidy. However, investments in eco-friendly technologies that would have been made at the same time even without the subsidy may not be taken as a direct impact of the subsidy (Beer, et al., 2000).
Such investors are termed 'free-riders'. The effectiveness of an environmental subsidy with no correction for free-riders is often referred to as 'pseudo-effectiveness' (Beer, et al., 2000).

A policy's true effectiveness can only be established after correction for free-riders. Put differently, the higher the percentage of free-riders, the lower a subsidy's effectiveness. Likewise, a policy's cost-effectiveness (see Section 2.3) declines when free-riders are factored in.

To allow for free-riders, for each policy it was established what percentage of those receiving the subsidy would have bought the same cleaner vehicle in the absence of the subsidy. Blok, et al., (2004) calculates that cost-saving policies have free-rider percentages of around 70% on average. For policies with no cost-savings the percentage of free-riders is considerably lower: between 5 and 15% for the SDE+ subsidy scheme, for example (CE Delft, 2017). In Chapter 3 we discuss how the free-rider percentage has been estimated for each policy measure.

In general terms, though, it may already be noted that it is no easy matter to estimate the number of free-riders. Although surveys and trend analyses can be used to obtain a more accurate figure, such methods are time-consuming and beyond the scope of the present study. For one policy MuConsult (2010) used a trend analysis to establish a free-rider percentage. For the other policies, though, free-rider percentages are unknown. These are also very hard to calculate, as we only know how many vehicles were sold following introduction of the policy. We therefore have no clear idea how many cleaner vehicles would have been sold in the policy's absence.

9 Fuel consumption data are for the fifth-generation Euro standards. Where necessary, these have ben adjusted for specific calculations.

10 GVW, Gross Vehicle Weight, indicates the maximum permissible vehicle weight.

This said, though, there are a number of criteria available with which a reasoned estimate can be made of the percentage of free-riders, including:

- Investment payback, i.e. how the end-user investment and subsidy payment compare. The less coverage from the subsidy, the lower the free-rider percentage will be.
- Signals from users (from review studies) that (uncertainty about) future environmental policy and extension of low-emission zones is making them worried about having continued access everywhere. In this case there is a good chance such users would have purchased a cleaner vehicle even without the subsidy scheme, leading to a higher free-rider percentage.
- Relationships with other environmental legislation. If the subsidy scheme is a component part of another environmental policy (like low-emission zones) then that other policy will also contribute to the number of people opting for a different vehicle. In itself, then, the subsidy scheme will have a lower free-rider percentage. In cases where there is direct dependence between the subsidy and another policy, it has been assumed by definition that there are no free-riders in the group moved to invest by the other policy.
- Free-ride rpercentages from other studies.

Despite these free-rider percentages being estimated with due care, the methodology employed has its shortcomings. For the analysis carried out by RIVM (cf. Section 1.1), however, it was necessary to adopt a single percentage.

2.3 Cost calculation procedure

In this study the cost-effectiveness of the various policies (in €/kg $PM_{2.5}$ and €/kg NO_x) was calculated from three different cost perspectives:

- **Government costs**: these are purely the costs borne directly by government. These include administrative costs[11], the subsidy payments made and changes in tax revenues (e.g. extra fuel-duty revenue if a policy leads to higher vehicle fuel consumption).
- **National costs** (using the standard Dutch 'Environmental Cost Methodology'): these are all the direct costs and benefits of the policy from the perspective of Dutch society as a whole. This does not include transfers like subsidies and taxes, as these remain available to society. Investment costs are important components, as are maintenance costs and fuel costs (minus fuel-duty). The administrative costs associated with the subsidies are also included.
- **End-user perspective**: the balance of all the direct costs and benefits for vehicle owners, including taxes and subsidies. VAT is included for private citizens, but not for companies.

2.3.1 Impact of free-riders on costs and effects

By adopting multiple cost perspectives it can be assessed whether a policy or technology constitutes an efficient investment from several perspectives, identifying its costs and/or benefits from each. The government costs and end-user costs indicate which parties shoulder what share of the cost burden. Free-riders affect cost-effectiveness in a variety of ways:

- National cost perspective: From this perspective the lower impact on emissions is compensated by the fact that free-riders incur zero costs.
- End-user perspective: Free-riders are not included in calculating these costs, thus compensating the lower impact on emissions. This means cost-effectiveness for end-users is independent of the percentage of free-riders.
- Government perspective: Because free-riders reduce the overall impact on emissions while still receiving subsidy, they have a negative impact on cost-effectiveness from the government

[11] These are the government's operating costs for rolling out the policy.

perspective. A higher percentage of free-riders leads to (relatively[12]) lower government cost-effectiveness, since the same subsidy payments are made for a smaller emission reduction, thus increasing the cost of unit emission reduction.

2.3.2 Cost components

For the cost-effectiveness calculations the following cost components were examined and quantified:
- investment costs;
- subsidy costs;
- fuel costs;
- AdBlue costs[13];
- maut costs[14];
- maintenance costs;
- VAT and fuel-duty;
- other variable costs.

The main sources for calculating the costs associated with each policy were review studies and interim reports. As necessary, these were supplemented by data from other literature.

The majority of subsidy cost data were provided by the Court of Audit, with a distinction sometimes made between subsidy payments and administrative costs. If this distinction was not made, administrative costs were assumed to be 4% of total costs, a percentage adopted in consulation with the Court. The subsidy costs of the Vehicle Purchase Tax discount were derived on the basis of the number of vehicles registered by the Netherlands Enterprise Agency (RVO, 2016).

Data on the fuel consumption of the various vehicle categories were taken from (TNO, 2016a). Over the years covered by the study there have been a variety of trends. Vehicles have become heavier as a result of safety requirements and because of purchase of relatively heavier vehicles (TNO, 2016a).On the other hand, technological improvements have made vehicles more fuel-efficient (TNO, 2016a). For HGVs TNO (2016a) reports that these have become 0.5% more efficient each consecutive manufacturing year. Actual reductions in fuel consumption occur stepwise as new vehicle models are introduced. An interview with TNO made clear that fuel-efficiency technologies are relatively divorced from those aimed at reducing particulate and NO_x emissions in connection with Euro standards. We have therefore assumed that vehicles complying with different Euro standards produced in the same year have the same fuel consumption. However, these standards do mean a difference in AdBlue consumption, as this depends directly on the emission-reduction technology employed.

Investment costs have been written of over the number of years a vehicle remains in the fleet. For retrofit particulate filters, the number of years the filter-fitted vehicle remains in the fleet was taken. The interest rate taken was 10% for end-users and 4% for the national costs, both figures following from VROM (1998). Maintenance costs, fuel costs and subsidy-related costs have all been taken on an annual basis.

12 A high percentage of free-riders does not automatically lead to high cost effectiveness. If substantial emissions reduction is acheieved at little cost, a policy will be efficiënt despite numerous free-riders.

13 AdBlue is a urea solution that needs to be separately filled up with if the car is fitted with a particular kind of catalytic converter (SCR). It reduces pollutant emissions by reacting with certain exhaust components.

14 The German ‘Maut’ toll system charges different tariffs according to the Euro standards met by the vehicle: the higher the standard, the lower the charge.

For each policy the costs (or benefits) per tonne avoided NO_x and/or $PM_{2.5}$ emission were calculated, factoring in a free-rider percentage (see Section 2.2.5). There are therefore no additional costs associated with free-riders, as the policy did not induce them to buy a different vehicle. This affects the end-user costs (which are reduced). The difference in fuel-duty is smaller, too, as the free-riders have no impact on fuel consumption since they are using the same vehicle they would have without the policy. This also knocks on in the national costs, which decrease with rising free-rider percentage.

2.3.3 Shadow prices

Besides the cost-effectiveness for NO_x and $PM_{2.5}$ individually, in this report a weighted cost-effectiveness in $PM_{2.5}$-equivalents was also calculated. By expressing NO_x and $PM_{2.5}$ emissions in shadow prices (€$_{2015}$) policies can be compared that affect either NO_x or $PM_{2.5}$ emissions or both. Shadow prices are based on damage costs, derived from epidemiological studies.

Using these shadow prices, the achieved reductions in NO_x and $PM_{2.5}$ emissions were also compared. Shadow prices for traffic NO_x and $PM_{2.5}$ emissions are provided in CE Delft (2017). For $PM_{2.5}$, emissions in three environments are distinguished: city, town and rural. This classification does not map onto the that comprising urban, rural and motorway. The costs in ‘city’ environments are highest, at € 600/t $PM_{2.5}$[15]. For ‘town’ they are € 200/t $PM_{2.5}$ and for ‘rural’ € 120/t $PM_{2.5}$.

A 10-20-70% split has been assumed between ‘city’, ‘town’ and ‘rural’, the same as reported by CBS, as can be seen in Table 4. This shows that 72% of $PM_{2.5}$ emissions and 78% of NO_x emissions occur on non-urban roads and motorways.

Table 4 - Road traffic NO_x and $PM_{2.5}$ emissions, 2015

	Motorways & non-urban roads	Urban
Million kg NO_x	58.7 (78% of total)	16.9
Million kg $PM_{2.5}$	1.59 (72% of total)	0.61

Source: Statline.

The weighted shadow price of $PM_{2.5}$ is thus € 168/kg $PM_{2.5}$ in €$_{2010}$, converting to € 183/kg $PM_{2.5}$ in €$_{2015}$[16]. For NO_x CE Delft (2017) reports a shadow price of € 34.7/kg.

[15] These are the costs in 2015.

[16] While Klein et al. (2017) report PM_{10} emissions, they also state that in the case of combustion emissions these fall enitirely in the category $PM_{2.5}$. As recent literature shows that $PM_{2.5}$ has by far the greatest health impact, moreover, PM_{10} has here been ignored.

3 Policies

In this chapter we consider each individual policy in turn, first describing the policy itself, then how its impacts and costs have been determined. In Chapter 4 the results are combined and the effects and costs of the eight policies compared.

3.1 National Scrappage Scheme

3.1.1 Policy description

The National Scrappage Scheme ran from 29 May, 2009 to 21 April, 2010. Under this scheme vehicle owners received a sum of between € 750 and € 1,750 on delivering their vehicle for scrappage on condition that they replaced it with a newer vehicle. Table 5 shows the subsidy level in force for the various categories of vehicle.

Table 5 - Scrappage subsidy per vehicle category

Vehicle category	Fuel	Year of manufacture	Subsidy
Passenger cars and vans	Petrol + LPG	up to 1989	€ 750
Passenger cars and vans	Petrol + LPG	1990-1995	€ 1,000
Vans, unladen weight < 1,800 kg	Diesel	up to 1999	€ 1,000
Vans, unladen weight > 1,800 kg	Diesel	up to 1999	€ 1,750
Passenger cars	Diesel	up to 1999	€ 1,000

3.1.2 Calculation method

The National Scrappage Scheme was already extensively review in 2010 by MuConsult, who made an accurate estimate of the types of vehicle scrapped and the vehicles with which they were replaced. MuConsult arrived at a figure of 83,444 scrapped vehicles, for which 83,444 newer vehicles were therefore purchased.

Since vehicle emission factors have since been better studied, we have here taken MuConsult's vehicle numbers but updated the emission factors based on CBS; PBL ; TNO; RWS, (2017). From MuConsult (2010) we know that the subsidy led to people buying a vehicle that was on average one year newer. The impact thus equalled the difference in emissions between the vehicle being scrapped and the new vehicle in 2010. MuConsult report that people drove 3% more kilometres with their newer vehicle than they would have done with the older one. The same assumption was made here.

Free-riders

MuConsult (2010) report a free-rider percentage of 9%, while the 'Option document on traffic emissions' (RIVM, 2004)takes a far higher figure: 40 tot 60%. The latter range is based on several assumptions, however. In CE Delft, 2010 ('Options for clean and efficient traffic. Impacts on climate change and air pollution'), too, a figure of 50% is taken, a percentage based on expert estimates by RAI and calculations using the passenger car model DYNAMO2.1. Here we have taken the figure reported by MuConsult (2010), because this was calculated using a trend analysis of the number of scrapped vehicles. A rounded figure of 10% was therefore taken as the free-rider percentage.

3.1.3 Calculated costs

According to MuConsult a total of 83,444 subsidies were granted, tallying to € 85 million in all. As the scrapped vehicles were replaced by newer models, the scheme had an impact on emissions of both NO_x and $PM_{2.5}$ (particulates). The policy meant a new vehicle was bought one year sooner than if there had been no subsidy scheme. We here assume no additional investment by vehicle users: while a new vehicle is purchased earlier, the subsidy does not mean they buy a different type of new vehicle. However, we do allow for the fact that the newer vehicles are heavier than the scrapped ones (MuConsult, 2010) . Because of more stringent safety regulations and for other reasons, the weight of light-duty vehicles increased by 7% over the period 2005-2015. This increase in weight means the new vehicles have higher fuel consumption, as reported in the consumption data documented by TNO (2015). This higher fuel consumption means a slight increase in end-user costs. We assumed here that annual maintenance costs remain unchanged. Because of the extra fuel-duty and VAT revenues, the government costs are slightly lower than the subsidy costs. The national costs comprise the investment costs, additional fuel costs and administrative costs.

3.1.4 Impacts and costs

The impact and costs of the policy are summarized in Table 6. The total emissions reduction was 0.77 kilotonne (kt) NO_x and 0.02 kt $PM_{2.5}$. The bulk of the costs derive from the actual subsidy payments: € 85 million, which means relatively high government costs. Under the assumption that the subsidy is invested in a new vehicle, the national costs are high, the result of the major investment made.

Table 6 - Avoided emissions, costs and cost-effectiveness of the National Scrappage Scheme

Emissions reduction	**Impact on NO_x (mln. kg)**	**Impact on $PM_{2.5}$ (mln. kg)**	**Combined impact (mln. kg $PM_{2.5}$-eq.)**
Cumulative reduction	0.77	0.02	0.16
Cumulative reduction corrected for free-riders	0.70	0.02	0.15
Reduction up to end of 2016	0.77	0.02	0.16
Reduction corrected for free-riders up to end of 2016	0.70	0.01	0.15
Costs	**End-user costs**	**Government costs**	**National costs**
Total	€ 849,000	€ 84,696,000	€ 93,012,000
Cost-effectiveness, NO_x (€ per kg NO_x)	€ 1	€ 122	€ 133
Cost-effectiveness, $PM_{2.5}$ (€ per kg $PM_{2.5}$)	€ 58	€ 5,785	€ 6,350
Cost-effectiveness, combined (€ per kg $PM_{2.5}$-eq.)	€ 6	€ 580	€ 637

Note 1: A breakdown of the various costs is provided in Appendix A.

Note 2: The combined cost-effectiveness makes allowance for reductions in both NO_x and $PM_{2.5}$. The damage due to 1 kg NO_x is approximately 0.19 of that of 1 kg $PM_{2.5}$. The combined impact is thus 0.70 * 0.19 + 0.02 = 0.15 mln. kg $PM_{2.5}$-eq. The combined cost-effectiveness is then calculated by dividing the costs by the emissions reduction, yielding a figure of € 849,000/0.15 mln. kg = € 6 per kg $PM_{2.5}$-eq. for the cost effectiveness from the end-user perspective.

3.1.5 Interpretation of results

The Scrappage Scheme was introduced primarily to clean up the vehicle fleet. A subsidiary aim was to support the automotive industry, which had been hit by the economic crisis (MuConsult, 2010). The auto maker's trade association consequently shared some of the burden of the subsidy investment. From MuConsult (2010) it also transpires that the ultimate results were overestimated in the *ex ante* study, which had assumed the impact would extend for four years, i.e. that people would have their vehicle scrapped four years earlier. This proved to be just one year, however, so the impact was four times less then predicted. These factors go some way to explain why this policy has a lower cost-effectiveness than the others. Given the shadow prices for the city environment, however, and these vehicles' relatively high urban mileage, a higher shadow price is warranted. In addition, it was also the acute air quality - problems in the urban environment (exceedance of EU Directive 2008/50) that led to policy action being taken. Local measures - the alternative - can prove more expensive.

3.2 Euro V incentive scheme

3.2.1 Policy description

The subsidy scheme to incentivize Euro V vehicles ran from 2006 to the end of 2011. Its aim was to stimulate sales of heavy-duty Euro V and EEV[17] vehicles. The incentive scheme was for HGVs, tractor units, buses and heavy-duty vans, which had to meet the Euro V standard by 1 September, 2009. From that date onwards, then, the subsidy scheme was in force only for EEV vehicles, which have tighter emission standards than Euro V vehicles.

Table 7 reports the subsidies in force for the various engine-capacity categories in the various periods. EEV vehicles were eligible for extra subsidy throughout the entire period the scheme was in force, because the purchase cost of these vehicles is higher (by around € 8,000) than that of a Euro V vehicle. Using average engine-capacity classes taken from TNO (2013), the number of subsidy applications was allocated across the vehicle categories. Annual sales figures of the vehicles in question were taken from CBS; PBL ; TNO; RWS, (2017) to establish the relative numbers of applications per vehicle category.

Table 7 - Subsidy per vehicle category (€)

Engine-capacity category (kW)	Period 1 1-10-2006 to 01-05-2008	Period 2 05-08 to 1-10-2009	Period 3 2009 to 1-10-2011
150	2,500	1,500	0
150-225	2,500	1,500	0
>225	2,500	500 (from 1-4-08)	0
EEV <225	5,000	2,500	1,000
EEV >225	5,000	1,500	1,000
Vans EEV+			500

3.2.2 Calculation method

In 2007 DHV conducted a preliminary review of the Euro V incentive scheme (DHV, 2007), discussing provisional results and reporting the number of subsidy applications.

During the first two periods (see Table 7) a Euro IV vehicle was taken as the reference, as the subsidy was geared specifically to incentivizing vehicle owners to replace their Euro IV vehicle with a Euro V or EEV vehicle. At the time the Euro V standard came into force for new vehicles it was only EEV vehicles that were eligible for the subsidy. From that moment on a Euro V vehicle was taken as the reference, which from 1 September of that year was available for purchase alongside EEV vehicles. Table 8 shows the calculated distribution of subsidy applications over the two reference vehicles. Tractor units, with the highest sales, received the greatest number of subsidies. Concession rules mean public transport buses must be EEV-compliant, leading to a relatively large proportion of subsidies for EEV buses. As of July 2009 extra-heavy vans (>2,800 kg) were additionally eligible for subsidy. As the scheme was changed soon after this date, it was mainly EEV vans that were sold. Because vehicles with a higher

[17] EEV stands for Enhanced Environmental Friendly Vehicle. In terms of emission limits this is a standard between Euro V and Euro VI, initially intended to distinguish gas-fuelled vehicles. For new vehicles sold in Europe there was no EEV obligation.

engine capacity were no longer eligible for subsidy during the final period, the ratio between subsidies for Euro V and EEV vehicles then changes.

Table 8 - Estimated numbers of subsidized vehicles

Vehicle category	Euro V vehicles	EEV vehicles
Light-duty HGVs	1,041	1,541
Medium-duty HGVs	3,796	2,012
Heavy-duty HGVs	4,796	523
Tractor units	14,847	1,855
Buses	318	2,542
Heavy-duty vans	3	986
Total	24,801	9,459

From vehicle numbers, mileage per road type and the difference in emission factors between Euro IV and Euro V or EEV vehicles the aggregate impact of the policy on emissions was calculated.

Free-riders

There are a range of factors and considerations of relevance for the estimated number of free-riders for the Euro V incentive scheme:
- The various Euro IV and Euro V incentive schemes introduced under the negotiated agreement on low-emission zones. An entrepreneur buying a Euro IV vehicle for such zones is therefore not by definition a free-rider, since without the incentive scheme the zones would in all likelihood not have materialized. However, Euro IV vehicles are also permitted in such zones up to the end of 2019, making it hard to estimate the extent to which these zones influenced Euro V vehicle purchase.
- There is no reason for an entrepreneur to purchase an EEV vehicle other than an anticipated tightening of the rules for low-emission zones. For buses, an EEV vehicle was compulsory under some concessions. This may possibly be connected with the attention value of the subsidy scheme and the fact there was a subsidy available.
- When the subsidy was in force there was er a lower Maut tariff for Euro V vehicles. The annual benefit to be reaped from a weekly return trip to Germany was around € 800. Many lighter HGVs will have lower mileage on German roads.
- Lower or higher fuel consumption is not an argument, as there are many uncertainties when a new vehicle is introduced.
- Many of the vehicles sold are heavy-duty HGVs, which often have over half their mileage on roads abroad and virtually none in low-emission zones. This group will benefit because of the lower Maut tariff.
- The subsidy generated positive interest in Euro V vehicles, leading to higher sales compared with Euro IV vehicles.

Based on these combined arguments a free-rider percentage of 50% was taken here.

3.2.3 Calculated costs

The subsidy gave full cost coverage for some vehicles but not for others. For EEV vehicles, particularly, the extra costs exceeded the subsidy. After deduction of the subsidy there remained an average investment of € 5,000 per vehicle. At the same time, though, the HGVs have lower Maut tariffs in Germany. For the sum total of vehicles the aggregate annual sum amounts to between € 6 and 10 million (see Table 24 in Appendix A). In addition, Euro V vehicles have (higher) AdBlue consumption, which means extra costs. The free-rider percentage is of no influence on the government's subsidy costs, but does affect end-user and national costs. This means both the latter work out lower than if there were no free-riders.

3.2.4 Impacts and costs

Table 9 reports the policy's impacts. Over the period 2006-2011 a total subsidy of around € 53 million was paid for almost 35,000 vehicles. On estimate, the policy resulted in a cumulative reduction of 34 mln. kg NO_x. Emissions of $PM_{2.5}$ rose a little because in practice Euro V vehicles have slightly higher per-kilometre emissions than Euro IV vehicles. The NO_x emissions are substantially lower, though.

End-user costs consist mainly of the extra investment to be made on top of the subsidy. As can be seen in Appendix A, there are lower Maut costs for the end-user but higher costs because of AdBlue consumption. Since fuel consumption remains the same, government costs consist solely of expenditure on the subsidy. From the national perspective, investment costs are the greatest.

Table 9 - Avoided emissions, costs and cost-effectiveness of Euro V incentive scheme

Emissions reduction	**Impact on NO_x (mln. kg)**	**Impact on $PM_{2.5}$ (mln. kg)**	**Combined impact (mln. kg $PM_{2.5}$-eq.)**
Cumulative reduction	34.50	-0.07	6.43
Cumulative reduction corrected for free-riders	17.25	-0.04	3.25
Reduction up to end of 2016	32.51	-0.09[18]	6.04
Reduction corrected for free-riders up to end of 2016	16.25	-0.04	3.02
Costs	**End-user costs**	**Government costs**	**National costs**
€ Total	€ 50,231,000	€ 53,222,000	€ 71,783,000
Cost-effectiveness, NO_x (€ per kg NO_x)	€ 3	€ 3	€ 4
Cost-effectiveness, $PM_{2.5}$ (€ per kg $PM_{2.5}$)	€ -	€ -	€ -
Cost-effectiveness, combined (€ per kg $PM_{2.5}$-eq.)	€ 16	€ 17	€ 22

Note 1: A cost breakdown is provided in Appendix A.

Note 2: For calculation of combined cost-effectiveness see Table 6, Note 2.

3.2.5 Interpretation of results

The Euro V incentivre scheme was introduced to help clean up the vehicle fleet in order to improve air quality in connection with low-emission zones. In retrospect, urban emissions of Euro V vehicles proved higher than anticipated based on the first vehicles, with a negative impact on the policy's cost-effectiveness. From the national perspective, though, this policy was nonetheless very cost-effective.

3.3 Euro VI incentive scheme

3.3.1 Policy description

The aim of the Euro VI incentive scheme was to increase the uptake of Euro VI heavy-duty commercial vehicles before the standards came into force. The scheme ran from 2012 to the end of 2013. Vehicles getting their license plates at the end of that year received the subsidy in 2014. The subsidy was € 4,500 for HGVs and € 1,500 for vans.

[18] Klein et al. (2016) report that a Euro V tractor unit has higher particulate emissions than its Euro IV counterpart. This is in contrast to other Euro V vehicles, which emit less than their Euro IV equivalent. Because tractor units are exported or scrapped sooner than other vehicles, the impact up to the end of 2016 is greater than the cumulative impact.

3.3.2 Calculation method

An RVO report on this subsidy scheme published in 2015 gives the number of vehicles per engine-capacity class (< 225 kW, 225-300 kW and >300 kW), with a breakdown by vehicle category. It has been assumed here that 30% of the mid-range HGVs and buses haven an engine volume < 225 kW. This means some of the subsidy applications below 225 kW are for this type of vehicle, alongside light-duty HGVs and heavy-duty vans. It as been assumed further that sales of vehicles of over 300 kW capacity are heavy-duty HGVs and tractor units. Vehicle numbers receiving a subsidy were estimated from sales figures (see Table 10).

The reference vehicle is a Euro V variant of the same vehicle, as these were on sale at the same time. Euro V vehicles emit more NO_x and $PM_{2.5}$ than Euro VI vehicles. The greatest reductions are for NO_x.

Table 10 - Subsidy applications per vehicle category

Vehicle category	2012	2013	2014
Heavy-duty vans	0	0	114
Buses	1	321	249
Light-duty HGVs	0	159	84
Mid-range HGVs	1	404	296
Heavy-duty HGVs	71	445	244
Tractor units	306	2,224	1,197

Free-riders

The argumentation regarding the free-rider percentage for the Euro VI incentive scheme is similar to that for the Euro V scheme.

- When the subsidy was in force the Maut tariff was not yet lower than than for Euro V vehicles, though there was a possibility of it being raised. The gains to be made on a return trip through Germany amounted to around € 800 per annum. Many of the lighter HGVs will have less mileage on German roads, however.
- The low-emission zone in the Maasvlakte 2 area had not yet been introduced when the subsidy was in force. Ultimately this was also opened to Euro V vehicles receiving their numberplates prior to 1-2013, though this was initially unclear. This uncertainty may have been a motive to purchase a Euro VI vehicle. Euro V vehicles bought while the scheme was in force have no access to Maasvlakte 2.

While the benefits of a Euro VI vehicle were not yet evident during the subsidy period, there will have been many purchases because of the uncertainties surrounding environmental zoning. A free-rider estimate of 50% was therefore taken.

3.3.3 Calculated costs

Euro VI vehicles sell for a higher price than Euro V vehicles. A study by ICCT (2012) on the additional costs for manufacturers cites a figure of $ 2,200 for incremental costs, to which overheads and a profit margin must be added. MNP, (2008) take a figure of between € 2,500 and € 4,000 for the sales price difference, depending on engine volume and we have adopted these figures here. For most vehicles this means the subsidy covered the costs. Other end-user benefits are a lower Maut tariff and lower costs associated with reduced AdBlue consumption (TNO, 2014). None of the costs are particularly high, as can seen from Table 24 in Appendix A. Government costs are € 28 million and consist solely of the subsidy itself, for 6,114 vehicles. The lower end-user costs have a positive effect on national costs: € 8 million, consisting largely of the extra investment costs for a new Euro VI vehicle. On average these are € 3,500 per vehicle, giving total investment costs of about € 14 million. This investment is partially offset by lower user costs.

3.3.4 Impacts and costs

The policy's main impact is to reduce NO_x emissions. For end-users the cost-effectiveness is negative, which for this group means that on balance they benefitted financially from the policy.

Table 11 - Avoided emissions, costs and cost-effectiveness of Euro VI incentive scheme

Emissions reduction	**Impact on NO_x (mln. kg)**	**Impact on $PM_{2.5}$ (mln. kg)**	**Combined impact (mln. kg $PM_{2.5}$-eq.)**
Cumulative reduction	7.20	0.05	1.40
Cumulative reduction corrected for free-riders	3.60	0.02	0.70
Reduction up to end of 2016	2.73	0.02	0.53
Reduction corrected for free-riders up to end of 2016	1.37	0.01	0.27
Costs	**End-user costs**	**Government costs**	**National costs**
€ Total	€ -9,247,000	€ 28,150,000	€ 8,347,000
Cost-effectiveness, NO_x (€ per kg NO_x)	€ -3	€ 8	€ 2
Cost-effectiveness, $PM_{2.5}$ (€ per kg $PM_{2.5}$)	€ -405	€ 1,233	€ 366
Cost-effectiveness, combined (€ per kg $PM_{2.5}$-eq.)	€ -13	€ 40	€ 12

Note 1: A cost breakdown is provided in Appendix A.

Note 2: For calculation of combined cost-effectiveness see Table 6, Note 2.

3.3.5 Interpretation of results

The national cost-effectiveness is € 12 per kg $PM_{2.5}$-eq. The 2015 shadow price for $PM_{2.5}$ is € 183 per kg. The emissions reduction cost € 12 per kg, while the damage would have cost € 183 per kg.
This means the subsidy scheme can be deemed cost-effictive from the national perspective.
The results for the Euro VI subsidy scheme are even better than for the Euro V scheme, because it had greater environmental benefits; Euro VI vehicles came up to expectations with respect to reduced emissions.

3.4 Subsidy scheme for particulate filters in new taxis and vans (STV)

3.4.1 Policy description

The subsidy scheme for particulate filters in new taxis and vans (STV) ran from 2006 to 2010 and aimed to encourage uptake of new taxis and vans with factory-fitted particulate filters, thus to reduce emissions. Although Euro 4 standards were in force at the time, some vehicle models were fitted with a filter (and consequently had lower particulate emissions) while others were not. As models with a particulate filter are generally dearer, the subsidy was an incentive for buyers to opt for a model fitted with one. With the arrival of Euro 5 vehicles, for which a particulate filter was essential to satisfy emission standards, more Euro 4 vehicles were also fitted with a particulate filter. The subsidy was € 400 per vehicle throughout the time the policy was in force.

3.4.2 Calculation method

In 2008 DHV carried out a preliminary review at the request of the environment ministry VROM which reports the number of subsidies granted up to the end of the first quarter of 2008. DHV also states that a steady 60% of taxis were sold with particulate filter. At the outset this figure was considerably lower for vans, though it rose over time. Data for 2009 and 2010 are reported in NL Agency's 2010 progress report on air-quality traffic policies.

In 2011 the residual budget was used, so numbers are also available for that year, as reported in Table 12. Emissions cuts were calculated by comparing the total emissions of a new Euro 4 vehicle with those of a new Euro 4 vehicle with a particulate filter.

Table 12 - Number of subsidies per vehicle category

Vehicle category	2006	2007	2008	2009	2010	2011
Taxis	1,040	2,307	1,824	1,348	2,262	497
Light-duty vans	199	1,077	1,722	810	746	37
Heavy-duty vans	1,507	10,672	19,082	14,412	17,699	1,187

Free-riders

The free-rider percentage was estimated to be 60%, a figure based on the review by DHV (2008), which indicates that:
- The subsidy did not cover user costs (€ 700 versus € 400 subsidy).
- Particulate filters lead to higher maintenance costs and fuel consumption.
- Vehicle owners report environmental concerns as the main reason for opting for a vehicle with a particulate filter.
- Corporate Social Responsibility (CSR). The STV financial incentive plays only a minor role.
- According to dealers, access to low-emission zones (or similar rules in the future) was the main reason (30%) for customers to buy a van with a particulate filter.
- Many models of taxis are only available with a particulate filter. For this group the free-rider percentage is therefore 100%.

As taxis were mostly available only with a particulate filter, it can be concluded that for 20% of applicants - the share of taxis - the availability of a subsidy played no role at all. For the remaining 80%, though, it did play a part. As the subsidy did not cover costs and was also not the main purchasing motive, 60% was taken as the free-rider percentage. This is merely an estimate, though.

3.4.3 Calculated costs

The cost of a particulate filter is covered only partly by the subsidy, with an additional € 300 investment required per unit (DHV, 2008). Additionally, particulate filters increase fuel consumption by 2.5% (CE Delft, 2008). A small increase in maintenance costs (around 5% per annum) was also assumed. Together, this means an increase in end-user costs. The overall cost breakdown is provided in Apppendix A.

3.4.4 Impacts and costs

Table 13 reports the policy's impacts. All in all 78,000 vehicles received a subsidy, totalling € 35 million. The policy only affects $PM_{2.5}$ emissions. The reduction is 1.19 mln. kg without correction for free-riders and 0.48 mln. kg with correction. The investment of € 700 per particulate filter plus the extra fuel consumption and extra maintenance costs mean national costs of € 44 million. The cost-effectiveness from the three perspectives varies from € 59 to € 94.

Table 13 – Avoided emissions, costs and cost-effectiveness of the STV incentive scheme

Emissions reduction	Impact on NO_x (mln. kg)	Impact on $PM_{2.5}$ (mln. kg)	Combined impact (mln. kg $PM_{2.5}$-eq.)
Cumulative reduction	0.00	1.19	1.19
Cumulative reduction corrected for free-riders	0.00	0.48	0.48
Reduction up to end of 2016	0.00	0.96	0.96
Reduction corrected for free-riders up to end of 2016	0.00	0.39	0.39
Costs	**End-user costs**	**Government costs**	**National costs**
€ Total	€ 38,670,000	€ 27,980,000	€ 44,480,000
Cost-effectiveness, NO_x (€ per kg NO_x)	-	-	-
Cost-effectiveness, $PM_{2.5}$ (€ per kg $PM_{2.5}$)	€ 81	€ 59	€ 94
Cost-effectiveness, combined (€ per kg $PM_{2.5}$-eq.)	€ 81	€ 59	€ 94

Note 1: A cost breakdown is provided in Appendix A.

Note 2: For calculation of combined cost-effectiveness see Table 6, Note 2.

3.4.5 Interpretation of results

As the subsidy for factory-fitted particulate filters was part of the negotiated agreement 'Reducing the particulate emissions of light-duty trucks, vans and campers' the budget for the subsidy was later increased. The subsidy's aim was to incentivize particulate filters before they became mandatory under the Euro 5 standards. From the national perspective the policy was cost-effective and the same holds for the government - perspective, as the benefits (schadow price) exceeded government costs.

3.5 Subsidy scheme for retrofit particulate filters in cars and light vans (SRL)

3.5.1 Policy description

The subsidy scheme for retrofit particulate filters in cars and light vans (SRL) ran from 1 July, 2006 to the end of 2010. The policy's aim was to incentivize particulate filters in vehicles already on the road. Initially, vehicle owners received € 500 subsidy, which was lowered to € 400 on 1 January, 2008.
In 2010 the subsidy was discontinued for lack of continued response.

3.5.2 Calculation method

The number of subsidies awarded up to the end of 2008 is reported in a review of the SRP scheme by TAUW (2009). Figures for 2009 and 2010 were derived from NL Agency's 2010 annual report on air-quality traffic policies. All in all almost 80,000 vehicles were retrofitted with a particulate filter, involving subsidies totalling nearly € 40 million. Data from CBS; PBL ; TNO; RWS, (2017) were used to estimate subsidy distribution across vehicle categories: 63,000 cars and 17,000 vans.

Table 14 - Estimated split of subsidy applications over vehicle categories

Vehicle category	2006	2007	2008	2009	2010
Passenger cars	3,759	45,933	11,339	1,300	297
Vans	1,203	13,780	2,155	169	36

Table 14 gives the number of vehicles per subsidy year. The TAUW review shows that owners of cars less than three years old scarcely made use of the scheme, many of these vehicles being factory-fitted with a particulate filter (TAUW, 2009).We assumed vehicles are on Dutch roads for nine years on average before being exported (TNO, 2015b). The vehicle age at which a particulate filter is installed was taken as four years, leaving five years' service life with a filter installed. The emissions reduction is the difference in emissions between a vehicle with and without a particulate filter during these five years. A four-year-old vehicle falls into the Euro 3 category. It was assumed that partial-flow particulate filters were the type installed[19].

Free-riders

As users benefit little from retrofitting a particulate filter, there are few free-riders. The review by TAUW (2009) indicates that environmental concerns were the main motive for fitting a filter and that the vehicle owners' own contribution was zero. The main reason for not fitting a particulate filter is financial. The (relatively) low owners' contribution is also cited as a reason for fitting a filter. From this it can be concluded that the subsidy level was the prime motive, which means a low free-rider percentage. As the number of people fitting a filter of their own accord is in all likelihood negligible, we assumed no free-riders.

3.5.3 Calculated costs

TAUW (2009) reports that fitting a particulate filter costs € 650 on average, compared with an average subsidy of € 480, which therefore did not cover costs. Based on expert TNO opinion, CE Delft (2008) reports a 1.5% increase in fuel consumption. A retrofit particulate filter will also increase maintenance costs slightly. Together, these factors mean a slight increase in end-user costs due to the subsidy scheme. The increased fuel consumption means more government revenue from fuel-duty and VAT. As this revenue is less than the outlay on the subsidy, though, on balance the policy involves government costs. The investment costs and extra operating costs mean relatively high national costs. This is also due to the low free-rider percentage. Virtually all costs can therefore be allocated to the policy, which had benefits in terms of reduced $PM_{2.5}$ emissions, but left NO_x emissions unchanged.

3.5.4 Impacts and costs

Table 15 sumarizes the policy's impacts. According to NL Agency (2011) total subsidy outlay was € 40 million. An estimated 80,000 vehicles had a particulate filter fitted, leading to a overall reduction of 0.13 mln. kg $PM_{2.5}$ emissions. The cost-effectiveness is between € 247 and € 605, depending on the cost-perspective.

[19] In a partial-flow particulate filter only part of the exhaust goes through a particulate trap, while in a closed filter it all does.

Table 15 - Avoided emissions, costs and cost-effectiveness of SRL incentive scheme

Type reductie	Impact on NO_x (mln. kg)	Impact on $PM_{2.5}$ (mln. kg)	Combined impact (mln. kg $PM_{2.5}$-eq.)
Cumulative reduction	0.00	0.13	0.13
Cumulative reduction corrected for free-riders	0.00	0.12	0.13
Reduction up to end of 2016	0.00	0.13	0.13
Reduction corrected for free-riders up to end of 2016	0.00	0.12	0.12
Type costs	**End-user costs**	**Overheid costs**	**National costs**
Total	€ 43,185,000	€ 31,385,000	€ 77,011,000
Cost-effectiveness, NO_x (€ per kg NO_x)	€ -	€ -	€ -
Cost-effectiveness, $PM_{2.5}$ (€ per kg $PM_{2.5}$)	€ 339	€ 247	€ 605
Cost-effectiveness, combined (€ per kg $PM_{2.5}$-eq.)	€ 339	€ 247	€ 605

Note 1: A cost breakdown is provided in Appendix A.

Note 2: For calculation of combined cost-effectiveness see Table 6, Note 2.

3.5.5 Interpretation of results

Thanks to an effective publicity campaign, the retrofit particulate filter scheme for passenger cars and vans led to a large number of filters being fitted in a short time. After 2008 interest soon tailed off, though. The impact was lower than anticipated beforehand because in 2009 partial-flow particulate filters proved to be less efficient than first thought, reducing emissions by 30% rather than 50%, which obviously knocks on in the cost-effectiveness, which is lower than that of most of the other policies.

It may be noted that the scheme was introduced at a time when there were numerous problems wth high particulate concentrations, with a serious economic impact. These arguments very likely played a major role in the decision to set up the subisidy scheme. The cost-effectiveness should therefore be assessed from the perspective of the air-quality problems the country was then facing.

3.6 Subsidy scheme for retrofit particulate filters in HGVs and buses (SRH)

3.6.1 Policy description

The subsidy scheme for retrofit particulate filters in HGVs and buses (SRV) ran from October 2006 to the end of 2011. During this period owners of heavy-duty vehicles were eligible for a subsidy for a retrofit particulate filter, which was essential for access to the low-emission zones that had started to come into force in various towns and cities from 2008 onwards. The main aim of the subsidy was to create public support for these zones. The subsidy level differed per vehicle category and changed over the years the subsidy was in force. Subsidies for heavy-duty vehicles with over 225 kW engine capacity were no longer available as of February 2008, for example, while subsidies for partial-flow particulate filters were discontinued at the beginning of 2009.

3.6.2 Calculation method

TAUW (2009) reports the total number of particulate filters fitted up to the end of 2008; figures for 2009 and 2010 were derived from NL Agency air-quality policy progresss reports. The residual budget is also known to have been depleted in 2011, permitting derivation of figures for 2011, too. Table 16 gives the estimated allocation across vehicle categories. TAUW (2009) reports, moreover, that only a very small number of Euro II vehicles were involved. Because emission factors are also lacking for these particulate filters, it was decided to include these as if they were Euro III. The split across vehicle categories is based on Euro III vehicles sales figures. The emissions reduction was calculated as the difference in emissions between a Euro III vehicle with and without a particulate filter. The average Euro III vehicle was manufactured in 2003 and had therefore been on the road for several years when the scheme came into force.

Table 16 - Estimated numbers of subsidized vehicles

Vehicle category	2007	2008	2009	2010	2011
Heavy-duty vans	155	746	230	228	171
Light-duty HGVs	747	2,727	841	834	625
Mid-range HGVs	2,716	1,091	336	334	250
Heavy-duty HGVs	3,327	273	0	0	0
Tractor units	10,088	405	0	0	0
Buses	557	165	51	51	38

Free-riders

The main aim of the SRH subsidy scheme for heavy-duty HGVs was to create public support for the introduction of low-emission zones. It was indeed integral to their creation and had been laid down in the negotiated agreement on 'Low-emission HGVs and low-emission zones'. TAUW (2009) also reports that access to these zones was also the main reason for fitting a particulate filter. Besides this, though, end-users gain little from particulate filters, as they mean extra maintenance and fuel costs. As these additional costs are low, though, the free-rider percentage is likely to be low. Since the subsidy was part and parcel of the introduction of low-emission zones, we assumed it was zero.

3.6.3 Calculated costs

TAUW (2009) reports that the cost of retrofitting a particulate filter is only covered by the subsidy for certain categories of vehicle. Overall, then, the policy required some measure of investment. Once installed, the filter means extra maintenance and fuel costs. Based on TNO, CE Delft (2008) reports a 1.5% increase in fuel consumption. Together, these factors mean increased end-user costs.

Table 25 in Appendix A shows that additional fuel costs are the largest cost item for end-users, followed by extra maintenance costs. For the government, higher fuel consumption means € 14 million extra fuel-duty revenue, a low figure compared with the € 150 million subsidy outlay. The investment costs and extra operating costs mean negative national costs of almost € 246 million, deriving mainly from the € 10,000 investment in the particulate filter (TAUW, 2009).

3.6.4 Impacts and costs

The calculations show that a total of 27,000 particulate filters were fitted for a total sum of € 152 million. The policy led to a $PM_{2.5}$ emission reduction of 0.47 mln. kg (without free-rider correction), but had no impact on NO_x emissions. The cost-effectiveness for end-users was € 120 per kg avoided emission, while the national cost-effectiveness was € 513 per kg avoided emission.

Table 17 - Avoided emissions, costs and cost-effectiveness of SRH incentive scheme

Emissions reduction	Impact on NO_x (mln. kg)	Impact on $PM_{2.5}$ (mln. kg)	Combined impact (mln. kg $PM_{2.5}$-eq.)
Cumulative reduction	0.00	0.47	0.47
Cumulative reduction corrected for free-riders	0.00	0.47	0.47
Reduction up to end of 2016	0.00	0.46	0.46
Reduction corrected for free-riders up to end of 2016	0.00	0.46	0.46

Emissions reduction	Impact on NO_x (mln. kg)	Impact on $PM_{2.5}$ (mln. kg)	Combined impact (mln. kg $PM_{2.5}$-eq.)
Costs	**End-user costs**	**Government costs**	**National costs**
€ Total	€ 57.308.000	€ 137.715.000	€ 246.232.000
Cost-effectiveness, NO_x (€ per kg NO)	€ -	€ -	€ -
Cost-effectiveness, $PM_{2.5}$ (€ per kg $PM_{2.5}$)	€ 120	€ 287	€ 513
Cost-effectiveness, combined (€ per kg $PM_{2.5}$-eq.)	€ 120	€ 287	€ 513

Note 1: A cost breakdown is provided in Appendix A.

Note 2: For calculation of combined cost-effectiveness see Table 6, Note 2.

3.6.5 Interpretation of results

Ex ante partial-flow particulate filters were estimated to be 50%-efficient, but in practice this proved to be only about 30%. As a result this scheme was less cost-effective than the others. The limited extension of vehicle service life also reduces cost-effectiveness. However, this policy too should be assessed in the broader context of the air-quality problems facing the country at the time.

3.7 Low-emission taxis and vans

3.7.1 Policy description

The subside scheme for low-emission taxis and vans ran from 2012 to 2015 and was introduced as an incentive for purchase of lower-emission vehicles in the following categories:
- Euro 6 diesel vehicles;
- hybrid vehicles;
- full-electric vehicles;
- CNG vehicles [20].

Under this scheme 2,408 vehicles were subsidized to a total of € 6.2 million. A breakdown by vehicle category is given in Table18.

Table18 - Subsidy per vehicle category

Vehicle	Euro VI	With LPG/CNG/Euro V/VI	$C0_2$ 50-95 g per km	CO_2 < 50 g per km	Full-electric
Subsidy	1,250	1,250	1,250	3,000	3,000

3.7.2 Calculation method

RVO (2016) reports the numbers of vehicles subsidized under this scheme and these figures were broken down to yield annual data, shown in Table 19. Up to the end of 2013 Euro 6 diesel vehicles were eligible for subsidy, but as of January 1, 2014 Euro 6 was mandatory for new vehicle models and subsidy for diesel engines was discontinued. From this date onwards the reference vehicle used in our calculations changes from a Euro 5 to a Euro 6 diesel vehicle.

[20] CNG stands for Compressed Natural Gas, an alternative for petrol or diesel with lower particulate and NO_x emissions.

Table 19 – Estimated numbers of subsidized low-emission vehicles

	2012	2013	2014	2015
Taxis, hybrid	0	0	1	1
Taxis, CNG	21	61	323	96
Taxis, Euro VI	66	194	0	0
Taxis, electric	15	46	243	72
Vans, CNG	15	45	241	72
Vans, Euro VI	82	243	0	0
Vans, electric	24	69	368	110

Free-riders

Based on sales figures a free-rider percentage of 50% was taken as a weighted average for the various vehicle categories, allowing for the following factors:
- The autonomous trend of a growing share of Euro 6 vehicles coming onto the market. Additionally, vans and taxis are increasingly found in urban centres where (future) environmental zoning is an key criterion. For this group we estimate a high free-rider percentage of 80%.
- As of 1 December, 2013 electric vehicles became eligible for an additional € 2,000 subsidy, an important factor for this category of vehicle, given the high share of applications from Amsterdam, around 60%; here the additional subsidy was in fact € 10,000. This meant a lower contribution from this subsidy scheme and a free-rider percentage of 40% for this vehicle category.
- For CNG vehicles fuel consumption declines (by about 40% compared with diesel). There are also factory-fitted vehicles on the market. Vehicles on 'green gas' are included in concession requirements. This means some of those applying for the subsidy would have bought a CNG vehicle without it. We estimated the free-rider percentage at 50%.

3.7.3 Calculated costs

Because of the very small number of applications for hybrid vehicles these were not included in the cost calculations. Costs were established for CNG, electric and Euro 6 vehicles relative to a Euro 5 vehicle. The sales price of alternatives to a Euro 5 vehicle is generally higher, apart from Euro 6 diesel passenger cars. AEA, (2011) found no evidence for introduction of a new Euro standard leading to a higher sales price for passenger vehicles. We therefore assumed the same price for Euro 5 and Euro 6 vehicles, while factoring in the urea consumption of the latter.[21]

In 2015 RVO carried out a TCO[22] for electric taxis which showed that additional purchase costs were partly offset by lower fuel and maintenance costs. For CNG vehicles we assumed higher purchase costs but lower fuel costs. On balance, the scheme's aggregate end-user benefit was € 3 million per annum. Given the reduced fuel consumption, there is € 5 million less government revenue, on top of the outlay on the subsidy itself. From the national perspective the lower fuel costs mean a positive balance. What this does not include, though, is the impact of possibly reduced availability of electric vehicles and to a certain extent also CNG vehicles. Appendix A provides a cost breakdown.

[21] While all Euro VI diesel passenger vehicles use AdBlue, the heavier models (of the day) often do. These were the models that first came onto the market.

[22] A Total Cost of Ownership (TCO) calculation, encompassing total vehicle lifetime costs, gives insight into the extent to which high investment costs are compensated by lower running costs.

3.7.4 Impacts and costs

This scheme's main impact was on NO_x emissions. Emissions of $PM_{2.5}$ increase very slightly because Euro 6 CNG vehicles have higher particulate emissions than Euro 6 diesels, as CBS; PBL ; TNO; RWS, (2017) report. The cost-effectiveness for NO_x varies from minus € 62 euro (i.e. a benefit) per kg NO_x for end-users to € 73 per kg NO_x for the government. Benefits are greatest from the national perspective.

Table 20 - Avoided emissions, costs and cost-effectiveness of incentive scheme for low-emission taxis and vans

Emissions reduction	**Impact on NO_x (mln. kg)**	**Impact on $PM_{2.5}$ (mln. kg)**	**Combined impact (mln. kg $PM_{2.5}$-eq.)**
Cumulative reduction	0.31	0.00	0.06
Cumulative reduction corrected for free-riders	0.16	0.00	0.03
Reduction up to end of 2016	0.15	0.00	0.03
Reduction corrected for free-riders up to end of 2016	0.08	0.00	0.01
Costs	**End-user costs**	**Government costs**	**National costs**
€ Total	€ -9,816,000	€ 11,528,000	€ -2,176,000
Cost-effectiveness, NO_x (€ per kg NO_x)	€ -62	€ 73	€ -14
Cost-effectiveness, $PM_{2.5}$ (€ per kg $PM_{2.5}$)	€ -	€ -	€ -
Cost-effectiveness, combined (€ per kg $PM_{2.5}$-eq.)	€ -331	€ 388	€ -73

Note 1: A cost breakdown is provided in Appendix A.

Note 2: For calculation of combined cost-effectiveness see Table 6, Note 2.

3.7.5 Interpretation of results

This scheme for low-emission taxis and vans was relatively cost-effective. Because it benefited end-users, a subsidy might be seen as superfluous. This is not the whole picture, though, as the benefits accrued mainly to electric and CNG vehicles, both of which have drawbacks: for the former, battery limitations, for the latter the poor infrastructure. In addition, the subsidy scheme was not aimed solely at air quality improvement, but also at implementing EU fuel diversification policy (RVO, 2016).
In parallel with this subsidy scheme other measures were also taken, including improvement of charging infrastructure where this was deficient. Despite the policy potentially having financial benefits for a certain user group, there was only modest interest in the scheme.

3.8 Vehicle purchase tax discount for Euro 6 diesel cars

3.8.1 Policy description

This scheme, giving a discount on the purchase tax paid on a Euro 6 diesel passenger car, ran from 2011 to 2013. The discount was € 1,500 in the first year, € 1,000 in the second and € 500 in the third.

3.8.2 Calculation method

A total of 13,647 Euro 6 vehicles were sold, the majority in the scheme's final year. As the subsidy was automatically paid, all such vehicles sold between 2011 and 2013 received it. The Netherlands Vehicle Authority (RDW) provided us with the number of Euro 6 cars registered each individual year, as reported in Table 21. The discount was designed to boost sales of Euro 6 diesel vehicles relative to their Euro 5 counterparts, so the latter was taken as the reference - vehicle. The policy's main effect was to reduce NO_x emissions, which were cut by 1.1 mln. kg.

Table 21 - Number of subsidies, subsidy level and total annual subsidy paid

	2011	2012	2013
Number of subsidies	446	1,624	11,577
€ per vehicle	1,500	1,000	500
Total	**€ 669,000**	**€ 1,624,000**	**€ 5,788,500**

Free-riders

There is no review of this policy, but CBS; PBL ; TNO; RWS, (2017) report low sales of vehicles with a Euro 6 engine while it was in force. In 2013, the subsidy's final year, 5% of sales were Euro 6. Given the minimal difference in price between the vehicles, the subsidy's main effect will have been to incentivize purchase of models with a Euro 6 engine. A drawback of the initial Euro 6 vehicles is their use of AdBlue. A free-rider percentage of 50% was taken, in line with RIVM (2012).

3.8.3 Calculated costs

Talks with TNO indicated that it is hard if not impossible to establish whether Euro 6 vehicles are more fuel-efficient than Euro 5 vehicles at the time of purchase. The former require AdBlue, though, which means additional costs for end-users. AdBlue consumption was assumed to be 3% of fuel consumption, a figure similar to that for the AdBlue consumption of Euro VI HGVs.

AEA, (2011) indicates furthermore that new Euro standards have no observable impact on the showroom price of passenger cars, which means purchase tax discount is ploughed back entirely as investment in the new vehicle. The costs of the subsidy were calculated by multiplying the subsidy by vehicle sales and adding 4% administrative costs. Government costs consist solely of outlay on the subsidy (see Appendix A). National costs are determined mainly by the lower fuel costs, leading on balance to benefits from the national perspective.

3.8.4 Impacts and costs

The policy led to 1.10 mln. kg NO_x emissions reduction without correction for free-riders and 0.55 mln. kg with correction. For $PM_{2.5}$ these figures were 0.21 and 0.10 mln. kg, respectively. Cost-effectiveness ranged from € 2 for end-users per avoided kg NO_x to € 15 for the govenment.

Table 22 - Avoided emissions, costs and cost-effectiveness of Euro VI vehicle puchase tax discount

Emissions reduction	**Impact on NO_x (mln. kg)**	**Impact on $PM_{2.5}$ (mln. kg)**	**Combined impact (mln. kg $PM_{2.5}$-eq.)**
Cumulative reduction	1.10	0.00	0.21
Cumulative reduction corrected for free-riders	0.55	0.00	0.10
Reduction up to end of 2016	0.67	0.00	0.13
Reduction corrected for free-riders up to end of 2016	0.34	0.00	0.06
Costs	**End-user costs**	**Government costs**	**National costs**
€ Total	€ 1,181,000	€ 8,418,000	€ 2,062,000
Cost-effectiveness, NO_x (€ per kg NO_x)	€ 2	€ 15	€ 4
Cost-effectiveness, $PM_{2.5}$ (€ per kg $PM_{2.5}$)	€ -	€ -	€ -
Cost-effectiveness, combined (€ per kg $PM_{2.5}$-eq.)	€ 11	€ 81	€ 20

Note 1: A cost breakdown is provided in Appendix A.

Note 2: For calculation of combined cost-effectiveness see Table 6, Note 2.

3.8.5 Interpretation of results

From the perspective of society as a whole, subsidization of Euro 6 diesel vehicles was a success, even though these vehicles had higher emissions than originally thought.

4 Synthesis

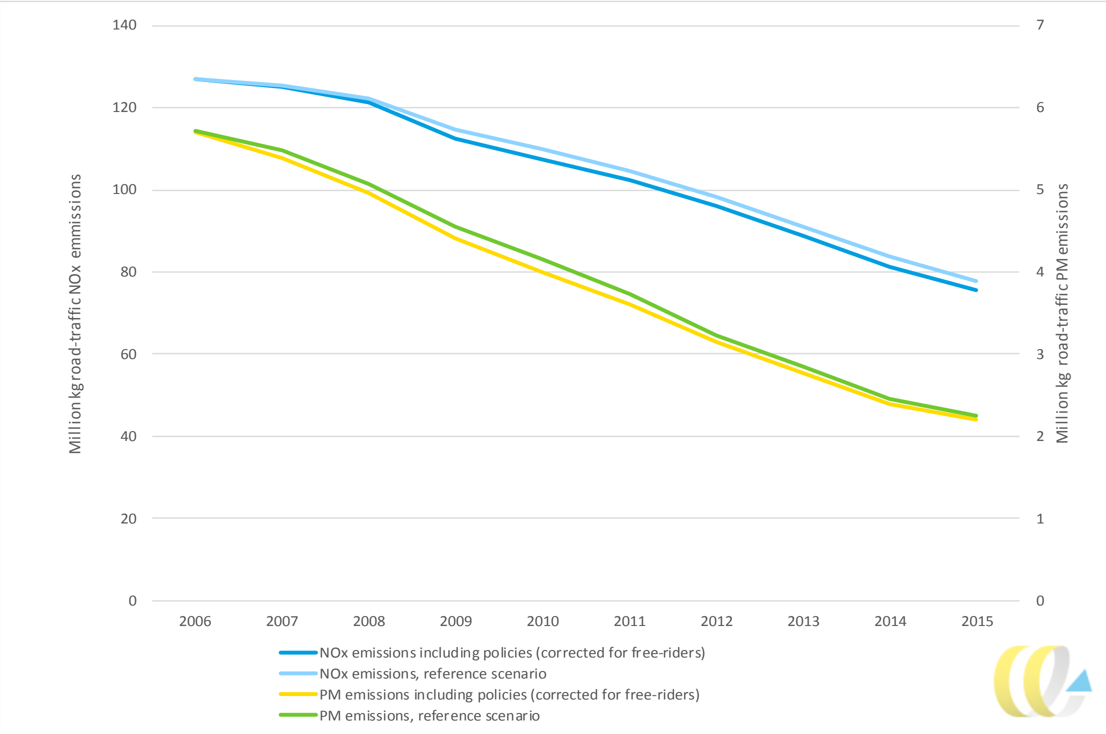
4.1 Introduction

In Chapter 3 it was explained how the emission impacts and costs of the individual policies were calculated. In this chapter we put together all the results and compare the policies' efficacy in terms of emissions reduction and cost-effectiveness.

4.2 Policy efficicacy

Figure 3 shows trends in emissions of NO_x emissions (left) and $PM_{2.5}$ (right). The lower lines indicate the emissions measured in practice, the upper lines those that would have occurred without the policies[23]. Between 2006 and 2015 the policies led on average to a 2% decrease in traffic emissions of $PM_{2.5}$ and NO_x. Table 23 provides a synopsis of all the results calculated in Chapter 3. Besides the impact on NO_x and $PM_{2.5}$ emissions, this table also shows the period the policy was in force, the number of vehicles affected and its total costs. There is considerable variation in these last three, which goes some way to explaining the emission reduction achieved.

Figure 3 - Trends in road traffic emissions with and without policies (mln. kg)



[23] This allows for free-riders. Without free-riders the differences would have been greater.

Table 23 – Synopsis of policies, costs and air-quality impact

Maatregel	Subsidy duration	Number of vehicles	Totale costs of subsidy scheme (€)	NO_x impact (mln. kg)	$PM_{2.5}$ impact (mln. kg)	NO_x impact corrected for free-riders (mln. kg)	$PM_{2.5}$ impact corrected for free-riders (mln. kg)	End-user costs (€)	Government costs (€)	National costs (€)
National scrappage scheme for cars and vans (Scrappage)	2009-2010	83,444	€ 85,120,000	-0.77	-0.02	-0.70	-0.01	€ 849,000	€ 84,696,000	€ 93,012,000
Subsidy scheme for new Euro V[24]/EEV HGVs and buses	2006-2011	34,260	€ 53,220,000	-34.50	+0.07	-17.25	+0.04	€ 50,231,000	€ 53,222,000	€ 71,783,000
Subsidy scheme for Euro VI HGVs and buses (Euro VI)	2012-2013	6,116	€ 28,150,000	-7.20	-0.05	-3.60	-0.02	€ -9,247,000	€ 28,150,000	€ 8,347,000
Subsidy scheme for new diesel taxis and vans with particle filter (STV)	2006-2010	78,428	€ 35,250,000	-	-1.19	-	-0.48	€ 38,592,000	€ 28,013,000	€ 44,432,000
Subsidy scheme for retrofitted particle filters in cars and light vans (SRL)	2006-2010	79,971	€ 39,780,000	-	-0.13	-	-0.13	€ 43,185,000	€ 31,385,000	€ 77,011,000
Subsidy scheme for retrofitted particle filters in HGVs and buses (SRH)	2006-2010	26,986	€ 151,820,000	-	-0.47	-	-0.48	€ 57,308,000	€ 137,715,000	€ 246,232,000
Subsidy scheme for new low-emission taxis and vans (LETV)	2012-2015	2,408	€ 6,450,000	-0.31	+0.00	-0.16	+0.00	€ -9,816,000	€ 11,528,000	€ -2,176,000
Purchase Tax discount for Euro 6 diesel cars (Euro 6 discount)	2011-2013	13,647	€ 8,080,000	-1.10	-0.00	-0.55	-0.00	€ 1,181,000	€ 8,418,000	€ 2,062,000

[24] To indicate the difference in Euro standards for passenger vehicles and HGVs, numbers are used for the former (e.g. Euro 5) and letters for the latter (e.g. Euro V).

4.3 Emissions reductions

The subsidy scheme for new Euro V/EEV HGVs and buses led to the greatest reduction in NO_x emissions, followed by the Euro VI scheme for HGVs and buses. It is noteworthy that the first of these caused a slight increase in $PM_{2.5}$ emissions, because the real-world emissions of several types of Euro V HGVs are slightly higher than those of Euro IV vehicles. Of the eight policies considered, the subsidy scheme for new taxis and vans with a factory-fitted particulate filter (STV) and that for HGVs and buses with a retrofit filter (SRV) led to the greatest reduction in $PM_{2.5}$ emissions. The emission cuts occurred in the Netherlands. Policies directed at vehicles with high mileage over the borders, such as the Euro V and Euro VI incentives and the SRH scheme, will also have led to reduced emissions abroad. The total impact may well have been twice as high. In addition, vehicles exported will also have had lower emissions in their country of destination. The policies will therefore have achieved (substantial) emission cuts outside the Netherlands, though these were beyond the scope of the present study.

4.4 Costs

Table 25 in Appendix A provides a breakdown of annual end-user costs. The cost item 'investment' is the annual investment sum. A value of zero means the subsidy gave full cost coverage, a positive value that an own end-user investment was required. The investment costs refer to the sum of the costs for the various vehicle categories. Subsidies may cover costs for different vehicle categories in different years. This does not mean this was the case for all the vehicles eligible for the subsidy in question. The other cost items indicate other factors contributing to the total annual costs. Particulate filters require extra maintenance, of relevance for the policies SRH, STV and SRL. Electric vehicles require less maintenance because the engines have fewer moving parts. This means the subsidy for low-emission taxis and vans led to lower maintenance costs. Euro V and Euro VI HGVs pay a lower Maut toll tariff in Germany and it was assumed one-third of the mileage on foreign roads was subject to Maut. The item 'fuel' indicates whether fuel costs increased or decreased, 'urea' whether AdBlue consumption was higher or lower. Together, these costs items represent the total annual costs.

The cumulative costs are reported in Table 25 in Apendix A. These costs were calculated with due allowance for free-riders and differences in how long vehicles remain in the fleet. End-user costs cannot simply be calculated on the basis of annual costs, because vehicles do not all remain in the fleet for the same number of years. Table 3 reports how long this is for the various vehicle categories.

Government costs are dominated by the costs associated with the subsidy. Higher or lower fuel-duty and VAT revenues generally play a far smaller role, though fuel-duty is more relevant for policies leading to major fuel savings, like the scheme for low-emission taxis and vans. Because no VAT is paid by businesses, VAT-related costs are zero for most policies.

National costs are governed by the investment required and the number of free-riders. Policies with a relatively high free-rider percentage have relatively lower investment costs compared with the total subsidy sum.

4.5 Cost-effectiveness

The cost-effectiveness of the various policies is shown in Figure 4. The costs are expressed Euro per avoided kg $PM_{2.5}$-equivalent[25]. Reductions in NO_x are thus expressed in terms of $PM_{2.5}$ emissions using shadow prices[26]. This allows NO_x and $PM_{2.5}$ emissions reductions to be compared and alllowance to be made for the fact that some policies reduce both. The downside of using $PM_{2.5}$-equivalents is that it is unclear what emission are reduced by what policy.

The cost-effectiveness of the policies should be compared with the average damage costs of € 183 per kg $PM_{2.5}$-eq. Particulate emissions have a greater impact in built-up areas. For policies with the greatest impact in the urban environment, the (avoided) damage costs can be as high as € 600 per kg $PM_{2.5}$ (cf. Section 2.3.3).

The policies Euro V, Euro VI, STV, LETV and Euro 6 discount have a national cost-effectiveness that is negative, i.e. lower than the shadow price. These are policies with more benefits than costs for society as a whole. They either have a small financial benefit for the end-user, or the costs are shared by the transport sector and government, as with a measure like low-emission zones. Although the end-user benefits are substantial in the case of low-emission taxis and cars, in evaluating this policy due allowance should be made for the risks surrounding the residual value of vehicles and the still limited availability of infrastructure,

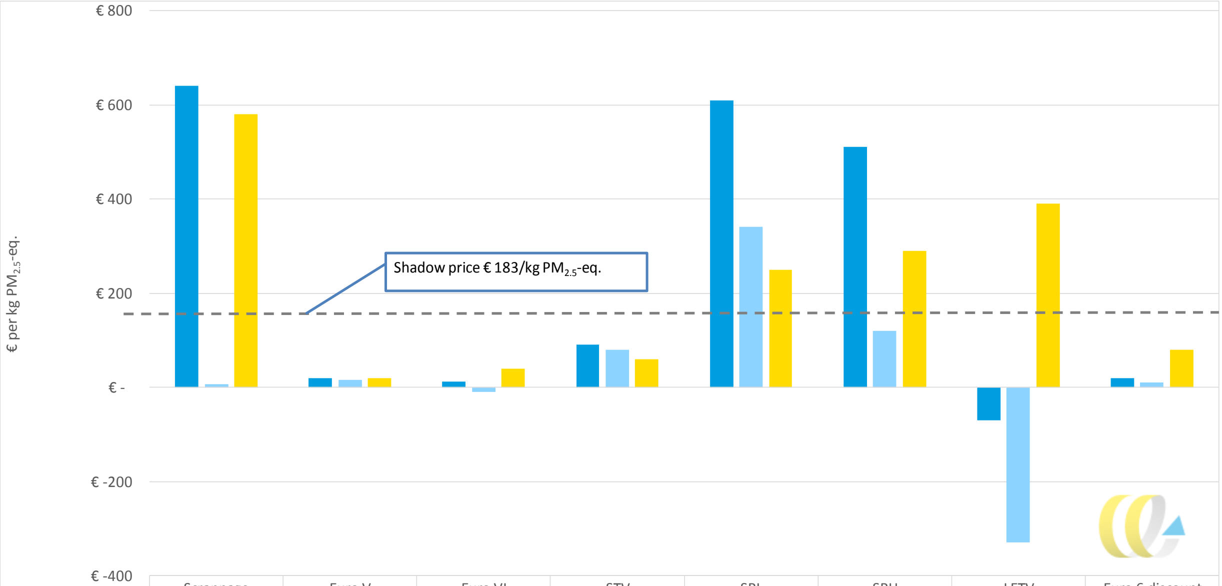
From the national perspective the SRL, SRH and the National Scrappage schemes are the least cost-effective. Although at first sight these policies may seem expensive, because some of them impinge mainly on urban traffic (Scrappage, SRL and to a lesser degree SRH) and these policies can help tackle urban air-quality hotspots, their cost-effectiveness should be considered in that light (cf. Section 4.7).

Finally, we would point out the difference in knowledge on a policy's efficacy prior to its introduction and new subsequent insights, which can affect its cost-effectiveness. This was particularly relevant for the subsidies for Euro 6 diesels, Euro V HGVs and the SRL and SRH schemes. We recommend accurately establishing beforehand how effective a particular technologoy is and testing this under real-world conditions. Additionally, there are also other criteris that need to be considered when reviewing the cost-effectiveness of air-quality policies. In the case of urban air-quality hotspots, for example, only a limited range of effective policies are available.

[25] A $PM_{2.5}$-equivalent expresses the damage due to an emission as if it were a $PM_{2.5}$ emission. 1 kg NO_x is approximately 0.19 times as damaging as 1 kg $PM_{2.5}$.

[26] 1 kg NO_x has a shadow price of € 34.7, 1 kg $PM_{2.5}$ a shadow price of € 184.

Figure 4 – Cost-effectiveness of the eight air quality policies, corrected for free-riders



	Scrappage	Euro V	Euro VI	STV	SRL	SRH	LETV	Euro 6 discount
National costs	€ 640	€ 20	€ 12	€ 90	€ 610	€ 510	€ -70	€ 20
End-user costs	€ 6	€ 16	€ -10	€ 80	€ 340	€ 120	€ -330	€ 10
Government costs	€ 580	€ 20	€ 40	€ 60	€ 250	€ 290	€ 390	€ 80

4.6 Remarks on estimated impacts

In this concluding section, we make several remarks on the reported results. These concern matters of potential influence on efficacy and cost-effectiveness that cannot be adequately quantified for lack of data or because they are beyond the scope of the present study.

Removal of particulate filters

From various sources there are indications that certain emission-reducing technologies are sometimes removed from vehicles. Particulate filters, for example, may be removed when they get clogged up. This holds not only for retrofit particulate filters but also for factory-fitted filters in vehicles receiving a subsidy,[27] A random survey of passenger cars by TNO revealed that 6% of particulate filters do not work even though the software gave no error message. The software was suspected to have been tampered with. There is also scope for getting around the use of AdBlue, with lower consumption leading to higher emissions.

These actions are illegal but are very hard to track down, making it impossible to estimate how widespread they are. Removal of emission-reducing technologies, or tampering with them, have consequently not been included in this review, also because it is unclear how much they increase emissions. This will undoubtedly be by a considerable amount, though.

[27] http://nos.nl/artikel/2076349-aanpakken-dieselsjoemelaars-nog-niet-zo-makkelijk.html

4.7 Shadow prices and location of emissions reduction

The shadow prices adopted here are based on the most recent values for the Netherlands, as reported in CE Delft (2017). For $PM_{2.5}$ there are several values, depending on the urbanization[28] of the emissions location, which will differ per policy and type of vehicle involved. It is beyond the scope of this study, however, to establish where emissions have occurred. It was assumed that on average 10% of emissions occur in a city environment, 20% in a town environment and 70% in rural areas. For policies associated more with built-up areas the $PM_{2.5}$ shadow price will be higher, while for those more relevant for rural areas it will be lower.

Our calculations were based on the average vehicle, which has an impact on estimated emissions reductions, as mentioned in Section 2.2.4. This is also of influence on the cost calculations. The longer technologies are on the market, the lower the additional costs will generally become. The price of retrofit particulate filters (SRH), for example, is known to have fallen in later years. This is proably the case for other technologies, too, but this cannot be factored in everywhere. A subsidy may therefore cover costs for one user but not for another.

[28] Urbanization is a measure of the population density based on the density of registerd addresses.

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A Cost breakdown

Table 24 - Breakdown of annual end-user costs

	Policy	Scrappage	Euro V	Euro VI	STV	SRL	SRH	LETV	Euro 6 discount
End-users	Total investment	€ -	€ 10,366,000	€ -678,000	€ 4,072,000	€ 3,402,000	€ -175,000	€ 1,154,000	€ -
	Maintenance	€ -	€ -	€ -	€ 1,847,000	€ 1,599,000	€ 4,156,000	€ -469,000	€ -
	Maut tariff	€ -	€ -6,325,000	€ -1,326,000	€ -	€ -	€ -	€ -	€ -
	Fuel	€ 944,000	€ -	€ -	€ 4,404,000	€ 3,081,000	€ 6,033,000	€ -3,849,000	€ -
	Urea	€ -	€ 6,189,000	€ -325,000	€ -	€ -	€ -	€ 21,000	€ 263,000
	Annual total	€ 944,000	€ 10,230,000	€ -2,330,000	€ 10,323,000	€ 8,083,000	€ 10,014,000	€ -3,143,000	€ 263,000

Table 25 - Breakdown of cumulative costs

	Policy	Scrappage	Euro V	Euro VI	STV	SRL	SRH	LETV	Euro 6 discount
End-users	Cumulative end-user costs	€ 849,000	€ 50,231,000	€ -9,247,000	€ 38,592,000	€ 43,185,000	€ 57,308,000	€ -9,816,000	€ 1,181,000
Government	Subsidy costs	€ 85,124,000	€ -53,222,000	€ -28,150,000	€ 35,246,000	€ 39,781,000	€ 151,819,000	€ -6,448,000	€ -8,418,000
	Fuel-duty revenues	€ 428,000	€ -	€ -	€ 7,232,000	€ 5,809,000	€ 14,104,000	€ -5,080,000	€ -
	VAT revenues	€ 136,000	€ -	€ -	€ -	€ 2,586,000	€ -	€ -	€ -
	Cumulative government costs	€ 84,696,000	€ 53,222,000	€ 28,150,000	€ 28,013,000	€ 31,385,000	€ 137,715,000	€ 11,528,000	€ 8,418,000
National	Investment	€ 89,722,000	€ 71,167,000	€ 13,984,000	€ 27,174,000	€ 58,868,000	€ 204,459,000	€ 5,360,000	€ 543,000
	Use	€ 3,291,000	€ 616,000	€ -5,637,000	€ 17,258,000	€ 18,142,000	€ 41,773,000	€ -7,536,000	€ 1,518,000
	Cumulative national costs	€ 93,012,000	€ 71,783,000	€ 8,347,000	€ 44,432,000	€ 77,011,000	€ 246,232,000	€ -2,176,000	€ 2,062,000

Note: The cumulative costs make allowance for the percentage of free-riders and the differences in how long vehicles remain in the vehicle fleet, data on which are provided in Table 3 in Chapter 2. The annual end-user costs in Table 24 provide an indication of the main items contributing to the cumulative costs.