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TNO report

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Tailpipe emissions of mopeds in the Dutch fleet

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Samenvatting

In steden rijden veel brommers en de populariteit van dit vervoermiddel neemt nog steeds toe. Brommers veroorzaken helaas ook overlast in steden, inwoners klagen over parkeeroverlast, stank, lawaai en rijgedrag. Ondanks het feit dat veel over de uitstoot van brommers (lees: brom- en snorfietsen) geklaagd wordt, blijkt uit diverse studies (Eijk & Stelwagen 2015 & Verbeek, 2015) dat de bijdrage van brommers aan bijvoorbeeld de NO_2 en PM_{10} concentraties beperkt is. Voor een aantal andere schadelijke stoffen is de bijdrage van het huidige brom- en snorfietsenpark aan de totale verkeersemissies wél aanzienlijk. Zo veroorzaken brom- en snorfietsen in Amsterdam ongeveer 31% van de door verkeer uitgestoten koolstofmonoxide en meer dan 23% van de koolwaterstoffen (Verbeek, 2015). Onderdeel van deze verzameling van koolwaterstoffen zijn onder andere de kankerverwekkende stoffen tolueen en benzeen.

De uitstoot van brom- en snorfietsen wordt, net als bij personen- en vrachtwagens, door Europese regelgeving (zogenaamde Euronormen) aan banden gelegd. Deze regelgeving is sinds 2002, echter, nauwelijks gewijzigd voor brommers. Daarentegen zijn de Euronormen voor bijvoorbeeld personenwagens sinds 2002 al meerdere keren aangescherpt met Euro 4, 5 en 6. Vanaf 2017 (Euro 4) en vanaf 2020 (Euro 5) komen brommers op de markt, die aan deze aangescherpte nieuwe emissie-eisen voldoen. Na de introductie van Euro 5, zijn de limietwaarden voor brommeremissies globaal gelijk aan die van de huidige Euro 6 personenvoertuigen.

Diverse steden in Nederland willen de overlast en mogelijke gezondheidsrisico's ten gevolge van brommeremissies snel terugdringen en overwegen uiteenlopende (lokale) beleidsmaatregelen. Om effecten van deze beleidsmaatregelen te kwantificeren is inzicht nodig in de emissieprestaties van de diverse type brom- en snorfietsen. Dit inzicht bestaat in de vorm van zogenaamde emissiefactoren, factoren die de hoeveelheid uitlaatgasemissies per gereden kilometer van de diverse type brom- en snorfietsen en emissiecomponenten weergeven. De huidige Nederlandse emissiefactoren zijn gebaseerd op diverse meetprogramma's van TNO. De factoren zijn soms al wat langer geleden vastgesteld of soms gebaseerd op slechts enkele type brommers.

Om de bestaande emissiefactoren voor brommers te valideren, op meer metingen te baseren en indien noodzakelijk te verfijnen, heeft TNO in opdracht van het Ministerie van Infrastructuur en Waterstaat en de steden Amsterdam, Nijmegen, Rotterdam en Den Haag een programma uitgevoerd om brommeremissies te meten. De resultaten van het meetprogramma leveren inzicht in emissieprestaties van 15 brommers en vormen een betrouwbare basis voor de validatie en eventuele verfijning van de Nederlandse set emissiefactoren voor brom- en snorfietsen.

Brommerselectie
De selectie bestaat voornamelijk uit Euro 2 en enkele Euro 3 brommers, brommers met carburateur en brommers met elektronische brandstofinjectie, met 2-takt en 4-takt motoren en uit snor- en bromfietsen. De meeste brommers zijn gebruikte exemplaren met uiteenlopende kilometerstanden. De brommers zijn gehuurd bij erkende brommerdealers. Van de Euro 3 brommer zijn drie brommers met een verschillende kilometerstand van hetzelfde merk en type getest. Op deze manier

wordt inzicht verkregen in de emissieprestaties van nieuwe en gebruikte Euro 3 brommers. Alle brommers waren, zover als bekend, in originele conditie. De volledige onderhoudshistorie is echter niet bekend van de gebruikte brommers. Opgevoerde brommers en brommers zonder snelheidsbegrenzers waren geen onderdeel van deze studie. In de praktijk hebben brommers zonder snelheidsbegrenzers mogelijk wat lagere emissies (Hensema, van Mensch & Vermeulen, 2013).

Test lab en opzet testen

Na de selectie van de brommers is allereerst de conditie van de brommers geïnspecteerd door de dealers. Denk hierbij aan de aanwezigheid van een origineel uitlaatsysteem en aan eventuele zichtbare defecten of aanpassingen. Na deze inspectie zijn de brommers naar het testlaboratorium in Biel (Zwitserland) gebracht. Dit laboratorium in Zwitserland heeft zeer veel ervaring op het gebied van tweewieler emissiemetingen en is volledig gecertificeerd om bijvoorbeeld ook officiële typekeur metingen uit te voeren. Alle gebruikte meetapparatuur, rollenbank etc. voldoen aan de gestelde eisen van Europese regelementen voor emissiemetingen. De testen zijn uitgevoerd onder begeleiding van TNO.

De brommers zijn vervolgens voorbereid en op een rollenbank getest waarbij een ritcyclus gereden werd die ook tijdens de Europese typekeuring gebruikt wordt, de zogenaamde ECE R47 cyclus. Deze cyclus bestaat uit 8 dezelfde opeenvolgende ritpatronen. De cyclus bevat delen die tijdens de praktijk veelvuldig voorkomen. Zoals vanuit stilstand vol-gas optrekken naar (bijna) maximumsnelheid, gevolgd door constant rijden en daarna afremmen naar een lagere snelheid (opgehouden door bijvoorbeeld fietsers) en afremmen naar stilstand.

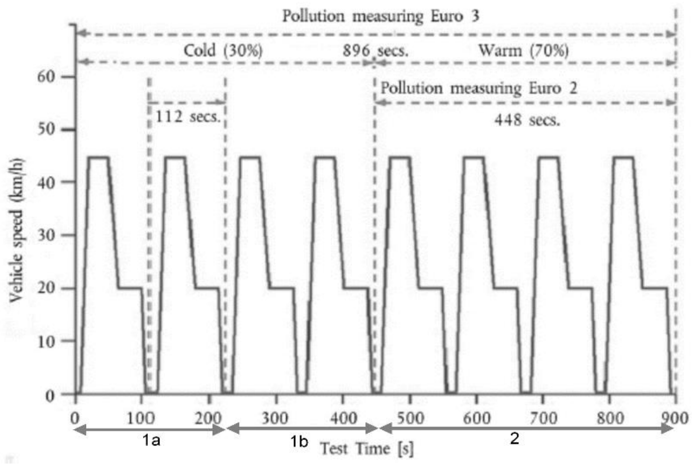


Figure 1: ECE R47 test cycle

Tijdens het onderzoek zijn niet alleen de totale emissies over de gehele rit vastgesteld, het meetprogramma is zodanig opgezet dat ook het effect van de koude start en het rijden op maximale snelheid op emissies en brandstofverbruik kon worden onderzocht. Iedere brommer in deze studie is tweemaal getest, dit leverde inzicht in de herhaalbaarheid van de meetresultaten en leverde de noodzakelijke informatie om aanvullende analyses te kunnen uitvoeren.

Tijdens de testen zijn de volgende componenten gemeten:

- Koolmonoxide (CO)

- Koolwaterstoffen (HC)
- Stikstofoxiden (NO_x)
- Koolstofdioxide (CO_2)
- Deeltjesmassa (Particulate Mass of PM_{10})
- Deeltjesaantallen (Particle Number of PN)

Tijdens de typekeuring van Euro 2 en Euro 3 brommers zijn alleen CO en $HC+NO_x$ (samengesteld) gereglementeerde emissiecomponenten. Voor PM en PN, en HC en NO_x afzonderlijk, zijn er geen typekeuringseisen voor deze brommers.

Resultaten
Onderstaande tabel geeft een overzicht van de gemiddelde uitstoot per brommer over de twee uitgevoerde tests. Om een onderlinge vergelijking mogelijk te maken zijn de koude start emissies (deel 1a en 1 b van figuur 1) in alle resultaten meegewogen. Hierdoor kunnen de resultaten van de Euro 2 brommers niet direct met de Euro 2 emissielimieten vergeleken worden. Het Euro 2 regelement schrijft namelijk voor dat de koude start emissies niet in de eindresultaten worden meegewogen. Volgens het Euro 3 regelement moet de koude start wél meegewogen worden in de eindresultaten. Daarnaast zijn tijdens delen van de test aan de bestuurder rijinstructies gegeven om vol-gas te geven tijdens de constante snelheidsgedeelten van de test. Dit is gedaan om meer inzicht in praktijkemissies te verkrijgen. Tijdens de typekeurprocedure wordt, afhankelijk van de maximumsnelheid van het voertuig, niet per se vol-gas gehandhaafd maar wordt de voorgeschreven constructiesnelheid aangehouden met een bepaalde marge.

Tabel 1: Brommeremissie resultaten, gemiddeld over twee testen, inclusief koude start.

Motor-type	**Max. snelheid**	**Euro Klasse**	**Voertuig ID**	**Merk / model**	**CO**	**THC**	**NO_x**	**HC + NO_x**	**PM**	**PN**	**CO_2**	**Brandstof verbruik**
	km/h		#	-	*g/km*	*g/km*	*g/km*	*g/km*	*mg/km*	*#/km*	*g/km*	*L/100 km*
2-stroke	25 km/h	Euro 2	1	Peugeot Fox[1]	4.11	3.95	0.04	3.99	242,5	1.48E+13	25.24	1,87
			2	Tomos Quadro[1]	10.46	4.82	0.01	4.83	86,6	1.20E+13	18.71	2,14
	45 km/h		3	Yamaha Aerox	15.32	3.48	0.01	3.48	57,1	3.38E+13	58.24	3,95
			4	Kymco Agility	6.96	10.11	0.22	10.32	261,9	4.66E+13	33.41	3,24
4-stroke	25 km/h		5	Piaggio Vespa	7.49	2.04	0.10	2.14	6,3	3.87E+12	61.38	3,37
			6	Kymco Agility	10.59	0.52	0.06	0.58	4,0	3.10E+12	45.15	2,69
	45 km/h		7	Piaggio Zip	4.66	0.86	0.22	1.08	2,9	3.06E+12	39.64	2,10
			8	Piaggio Zip	6.34	0.90	0.13	1.03	12,9	4.19E+12	36.75	2,10
			9	La Souris	13.04	1.19	0.15	1.34	4,6	3.42E+12	35.79	2,54
			10	Peugeot Vivacity	20.32	1.55	0.08	1.63	9,0	2.93E+12	36.74	3,12
			11	Honda NSC*	0.44	0.36	0.26	0.63	1,9	1.00E+12	41.83	1,85
			12	Baotian Rebel	8.33	0.64	0.19	0.82	10,1	5.90E+12	35.19	2,13
		Euro 3	13	Piaggio Liberty*	1.81	0.92	0.32	1.24	5,9	2.62E+12	43.90	2,10
			14	Piaggio Liberty*	2.02	1.14	0.42	1.56	7,8	1.55E+12	45.53	2,22
			15	Piaggio Liberty*	2.05	1.02	0.35	1.37	5,5	2.87E+12	43.01	2,10

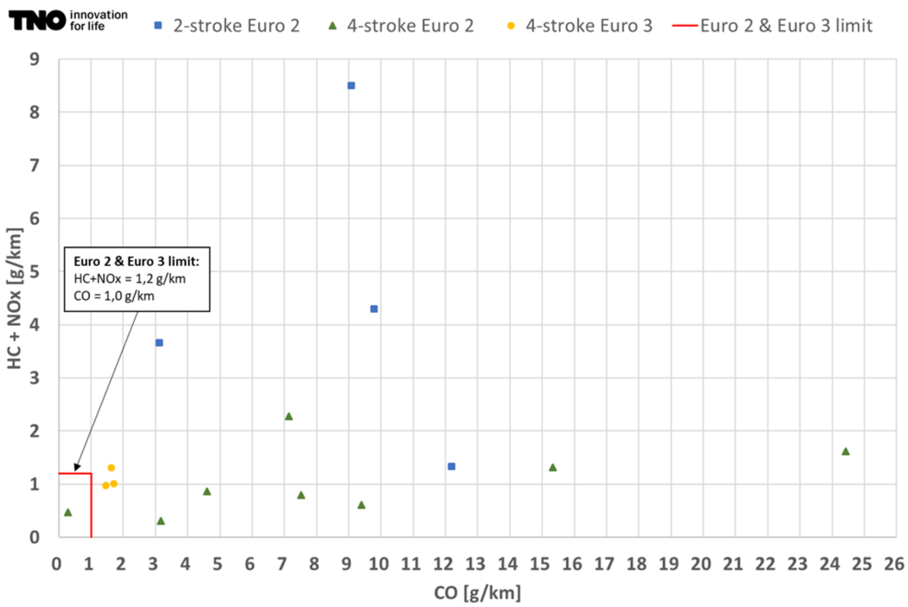
* Brommers met elektronische brandstof injectie in plaats van carburateur

[1] Van de Peugeot Fox en de Tomos Quadro is niet met zekerheid te zeggen of dit Euro 2 brommers zijn. Volgens de RDW-website is de datum van eerste toelating van deze brommers 31-08-2005. Bij de overgang van de brommerregistratie naar de RDW, zijn brommers met bouwjaren van 2005 of ouder met datum van eerste toelating van 2005 geregistreerd. De emissieprestaties van deze brommers liggen op hetzelfde niveau als de andere 2-takt Euro 2 brommers.

De emissies van de verschillende brommers lopen sterk uiteen. In het algemeen kan gesteld worden dat 2-takt brommers aanzienlijk meer deeltjes (PM_{10} en PN) en koolwaterstoffen (HC) uitstoten dan 4-takt brommers. De 4-takt brommers stoten weer iets meer NO_x uit dan 2-takt brommers. Brommers met elektronische brandstofinjectie stoten minder koolmonoxide (CO), koolwaterstoffen en deeltjesaantallen (PN) uit dan brommers met een carburateur. Opvallend is dat brommers met brandstofinjectie wel meer NO_x uitstoten dan de andere brommers. Dit geldt in het bijzonder voor de Euro 3 variant, waarvan de toegepaste technologie naar verwachting de basis zal zijn voor Euro 4 brommers.
De CO_2-uitstoot en het brandstofverbruik van de geteste brommers 4-takt brommers is redelijk vergelijkbaar. De 2-takt 45 km/h brommers laten het hoogste brandstofverbruik zien. Daarna volgen de 4-takt 25 km/h snorfietsen. De 2-takt 25 km/h snorfietsen hadden het laagste brandstofverbruik. Dit zijn snorfietsen met een laag gewicht en een laag vermogen.

Tot op heden zijn in de Euronormen eisen gesteld aan de uitstoot van CO en HC + NO_x (gecombineerd). In onderstaande figuur zijn de testresultaten voor HC + NO_x versus CO en zijn de geldende Euro limieten weergegeven. Ondanks dat de weergegeven meetresultaten niet gelden als officiële typekeurresultaten, is de uitvoering van de test en de dataverwerking (voor dit specifieke figuur) grotendeels vergelijkbaar met de procedure tijdens de typekeuring. Dat wil zeggen, dat voor dit figuur de koude test fase niet is meegenomen in de resultaten van de Euro 2 brommers. Daarnaast zijn voor dit figuur de testresultaten geselecteerd waarbij de rijinstructie was om de maximale constructiesnelheid (25 of 45 km/h) aan te houden in de test. Echter, de meeste voertuigen waren gebruikt en de testvoorbereiding week op bepaalde details af van de typekeurprocedure.

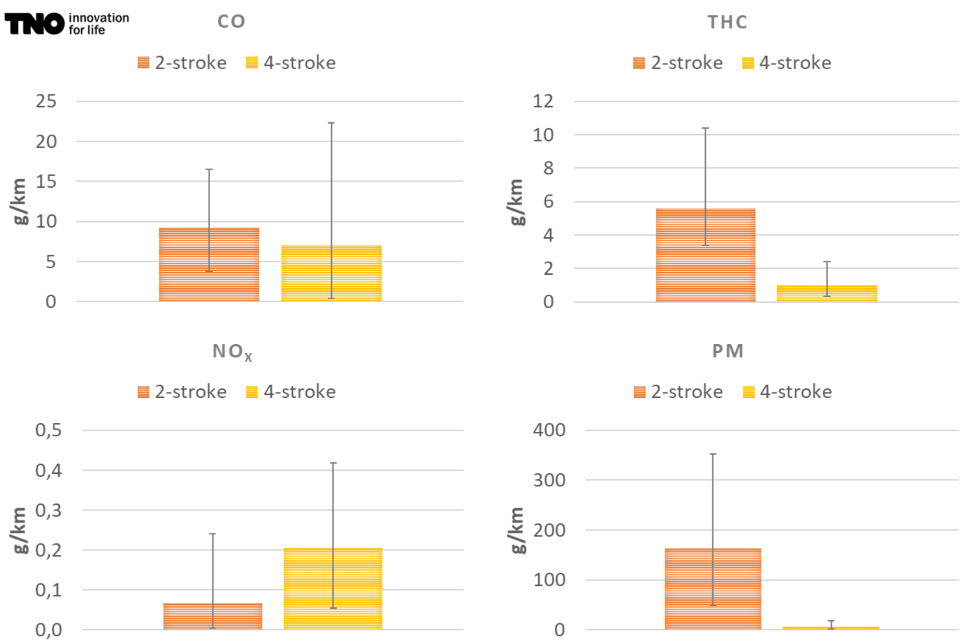
Uit het onderstaande figuur komt duidelijk naar voren dat slechts een van de vijftien brommers voldoet aan de limieten van de typekeuring. Dit is opvallend omdat twee van de 4-takt Euro 2 brommers slechts 250 km hadden gereden voorafgaand aan de test (zoals voorgeschreven). De Euro 2 brommer die binnen de emissielimieten presteert, is het voertuig met elektronische brandstofinjectie en had een kilometerstand van 4000 km. De drie Euro 3 brommers zitten ten opzichte van de andere brommers dichtbij de limieten.



Figuur 2: Emissieresultaten van de 15 geteste brommers in vergelijking met de typekeuringslimieten.

Resultaten 2-takt versus 4-takt

Om de uitstoot van 2-takt en 4-takt brommers eenvoudig te kunnen vergelijken is de gemiddelde uitstoot van de gemeten luchtverontreinigende stoffen van de 2-takt en 4- takt brommers bepaald en weergegeven in onderstaande figuren.



Figuur 3: Emissieresultaten gemiddeld voor 2-takt en 4-takt brommers.

Uit deze vergelijking volgt dat 2-takt brommers gemiddeld bijna 25 keer meer deeltjesmassa uitstoten dan 4-takt brommers. Gemiddeld stoten de 2-takt brommers bijna 5 keer meer HC uit dan de 4-takt brommers. De gemiddelde CO-uitstoot verschilt niet veel. De gemiddelde NO_x uitstoot van 4-takt brommers is hoger dan van 2-takt brommers. De zwarte verticale lijn geeft de spreiding van de resultaten aan, deze laat zien dat de spreiding van de uitstoot binnen de verschillende emissiecomponenten zeer groot is.

Vergelijking meetresultaten en emissiefactoren
Een belangrijk doel van het meetprogramma is om inzicht te verkrijgen in de emissieprestaties van een flink aantal voor het Nederlands brommerpark representatieve brommers. Dit moet een degelijke basis vormen om de bestaande brommeremissiefactoren te valideren en waar nodig aan te passen. Onderstaande tabel geeft een overzicht van de huidige Nederlandse brommeremissiefactoren voor standaard (niet opgevoerde) brommers.

Tabel 2: Huidige Nederlandse emissiefactoren voor Euro 2 brommers

Moped type		Euro-Class	CO [g/km]	THC [g/km]	NO_x [g/km]	THC + NO_x [g/km]	PM_{10} (exhaust) [g/km]
2-stroke	25 km/h	Euro 2	5,63	5,27	0,12	5,39	0,07
	45 km/h	Euro 2	4,79	4,38	0,10	4,47	0,06
4-stroke	25 km/h	Euro 2	24,1	1,75	0,04	1,79	0,01
	45 km/h	Euro 2	18,4	1,23	0,04	1,27	0,01

De meetresultaten van de 15 brommers zijn per brommertype gemiddeld en weergegeven in onderstaande tabel.

Tabel 3: Gemiddelde emissies per brommertype op basis van de metingen

Engine type	**Speed**	**Euro class**	**CO** *g/km*	**THC** *g/km*	**NOx** *g/km*	**HC+NOx** *g/km*	**PM** *g/km*	**PN** *#/km*
2-stroke	25 km/h	Euro 2	7.29	4.39	0.02	4.41	0.16	1.3E+13
	45 km/h		11.14	6.79	0.11	6.90	0.16	4.0E+13
4-stroke	25 km/h		9.04	1.28	0.08	1.36	0.01	3.5E+12
	45 km/h		8.86	0.92	0.17	1.09	0.01	3.4E+12
		Euro 3	1.96	1.03	0.36	1.39	0.01	2.3E+12

De meetresultaten kunnen niet zonder meer met de Nederlandse emissiefactoren vergeleken worden. Daarvoor zou bijvoorbeeld ook gecorrigeerd moeten worden voor afwijkende gemiddelde ritlengte en het aandeel van de koude start. Toch geven de meetresultaten een indicatie of de emissiefactoren in absolute zin in de goede richting wijzen en meer nog geeft de onderlinge vergelijking een goed beeld of de veronderstelde verschillen tussen brommertypes juist zijn.
Algemeen mag gesteld worden, zeker ook gezien de spreiding in de meetresultaten, dat de huidige emissiefactoren op hoofdlijnen overeenkomen met de meetresultaten. De meetresultaten zullen gedeeld worden met het overlegorgaan GCN/GDN (een samenwerking onder supervisie van het RIVM tussen verscheidende ministeries, PBL, TNO en RWS) en ten behoeve van het

NSL (Nationaal Samenwerkingsprogramma Luchtkwaliteit). Eventuele aanpassingen van de emissiefactoren zullen naar verwachting beperkt zijn.

CO
De gemiddelde CO meetresultaten van 2-takt Euro 2 brommers zijn hoger dan de overeenkomstige emissiefactoren, voor 4-takt brommers is dit net andersom.
Op CO uitstoot lijkt Euro 3 een grote verbetering te betekenen.

HC
De meetresultaten voor koolwaterstoffen komen redelijk overeen met de huidige Euro 2 emissiefactoren. Alleen de HC emissiefactoren voor 2-takt Euro 2 snorfietsen zijn wat lager dan de meetresultaten. Er lijken geen grote verschillen tussen Euro 2 en Euro 3 te zijn.

NO_x
De gemeten uitstoot van (NO_x) stikstofoxide van 4-takt Euro 2 brommers is hoger dan de overeenkomstige emissiefactoren. Vooral de NO_x uitstoot van de 4-takt Euro 2 brommer met brandstofinjectie is hoog. De 4-takt Euro 3 exemplaren, ook met brandstofinjectie, presteren slechter dan de huidige 4-takt Euro 2 brommers. Dit is een aandachtspunt, aangezien de geteste Euro 3 brommers voor wat betreft toegepaste technologie representatief geacht worden voor Euro 4 brommers.

PM_{10} / PN
De gemeten deeltjes uitstoot van 4-takt Euro 2 brommers komt goed overeen met de emissiefactoren, de gemeten deeltjes uitstoot van 2-takt Euro 2 brommers ligt hoger dan de huidige overeenkomstige emissiefactor.

Conclusies
Door de toenemende aandacht voor brommeremissies worden emissiefactoren voor de diverse type brom- en snorfietsen meer relevant. De recente metingen aan de 15 brom- en snorfietsen laten zien dat brommeremissies over het algemeen hoog zijn. Dit geldt ook voor de gemeten nieuwe Euro 2 brommers.
De meetresultaten komen op hoofdlijnen redelijk overeen met de bestaande emissiefactoren. Echter, voor 4-takt brommers lijken CO-emissies lager en de NO_x emissies hoger dan de bestaande emissiefactoren.
Voor 2-takt brommers lijken de gemiddeld gemeten emissies hoger dan de bestaande PM emissiefactoren. De nieuwe dataset biedt een goede basis voor update van de brommeremissiefactoren.

Een opvallende bevinding uit het meetprogramma is de toename van de CO uitstoot bij 7 van de 12 Euro 2 brommers na de koude start fase. Normaal gesproken zou verwacht mogen worden dat de katalysator in de uitlaat juist beter gaat werken bij hogere temperaturen. Dit wijst op een zeer beperkte levensduur van de katalysatoren op een groot deel van de brommers. De brommers met elektronische brandstofinjectie, waaronder ook de Euro 3 brommers laten wel een duidelijk afname van emissies zien na de koude start fase.

De drie gemeten Euro 3 brommers van hetzelfde model presteren, ondanks de verschillen in kilometrages, vrijwel identiek en scoren goed op CO, HC en PM/PN emissies. Voor dit geteste type voertuig blijven de emissiecontrolesystemen ook over langere tijd goed presteren. Deze Euro 3 brommer met elektronische brandstofinjectie heeft, in tegenstelling tot de meeste andere geteste brommers, nagenoeg geen meerverbruik ten gevolge van het rijden met “vol gas”. Het negatieve effect van snelheidsbegrenzers op het brandstofverbruik is voor dit type brommer minder relevant. Tot op heden was er weinig aandacht voor NO_x emissies van brommers. De relatief hoge NO_x emissies van de onderzochte 4-takt Euro 3 brommers zijn een aandachtspunt; deze liggen op het niveau van moderne Euro 6 diesel personenauto’s. Hoewel er maar weinig Euro 3 brommers verkocht zijn in Nederland, is de toegepaste technologie naar verwachting de basis voor Euro 4 brommers. Dit kan aanleiding zijn om aan de emissiefactoren een aparte categorie Euro 3 toe te voegen.

Discussie

Met de implementatie van de nieuwe Europese emissie-eisen voor Euro 4 (2017) en Euro 5 (2020) worden aanzienlijk strengere eisen aan brommeremissies gesteld en zou daarmee op termijn de uitstoot van de brommervloot flink gereduceerd moeten worden. De technologie om brommers aan deze nieuwe eisen te laten voldoen wordt echter complexer. De gewenste lage emissieniveaus worden alleen gerealiseerd indien de geavanceerde technologie ook in de praktijk daadwerkelijk goed functioneert. Monitoring van praktijkemissies van brommers lijkt een belangrijk instrument om dit te valideren. Deze metingen worden bij voorkeur dan ook op de openbare weg, onder representatieve praktijkcondities uitgevoerd. In navolging van het personen- en vrachtverkeer moeten brommeremissies in de toekomst niet alleen in een laboratorium maar ook met mobiele meetapparatuur op de weg gemeten worden. TNO onderzoekt momenteel de betrouwbaarheid van dergelijke mobiele meetapparatuur om in de nabije toekomst brommeremissies op de weg te kunnen meten. De apparatuur hiervoor is nog volop in ontwikkeling en momenteel nog niet op het niveau om nu al op grote schaal in te zetten.

De effecten van de invoering van nieuwe emissiewetgeving worden pas merkbaar nadat een flink deel van de brommervloot vervangen is door nieuwe brommers. Uitgaande van de leeftijdsopbouw van de brommervloot en van de introductie datums van Euro 4 en met name Euro 5 zal dit tot ongeveer 2025 duren. Lokale beleidsmaatregelen zoals milieuzones en/of sloopsubsidies kunnen de verschoning lokaal aanzienlijk versnellen

Contents

1 Introduction

1.1 Background

Road-traffic emissions are significant contributors to air quality degradation. In particular in urban areas traffic emissions affect the human living space. Many inhabitants, in particular of metropolitan areas in the Netherlands, complain about driving behaviour, noise and stench of mopeds. At the same time mopeds become increasingly popular, in some cities the number of mopeds almost doubled over the last decade (Verbeek, 2015). Although mopeds still correspond to a rather small fraction of total road transport activity, they do contribute significantly to HC and CO emissions in specific areas (Verbeek, 2015 & Eijk, 2015) this may have a negative impact on health. For example, in the city of Amsterdam, mopeds do emit 31% of the total road traffic related CO emissions and 23% of the total road traffic related HC emissions (Verbeek, 2015).

Dutch moped fleet
By European law, mopeds have an engine capacity smaller than 50cc which distinguishes them from motorcycles. In the Netherlands two different categories of mopeds are available:
a) Mopeds with a maximum construction speed of 45 km/h, used with helmet, on the road;
b) Mopeds with a maximum construction speed of 25 km/h, used without helmet, on the bicycle lanes.

Both categories are sold with 2-stroke and 4-stroke engines. However, the 4-stroke models are more popular.

To reduce emissions from mopeds, the European Commission introduced several stages of emissions control regulation since 1997. Directive 97/24/EC defined emissions limits up to Euro 3. Since 2017, Euro 4 is implemented with more stringent emission limits. The majority of the mopeds in the Netherlands are Euro 2 mopeds. However, a limited number of Euro 0 and Euro 1 mopeds remain driving in the cities. Although the Euro 3 emission standard was introduced in 2014, Euro 3 mopeds are hardly sold and are rarely seen in the Netherlands. This is a result of the emission legislation, after the introduction of the Euro 3 standard, manufacturers were still allowed to sell Euro 2 mopeds. As Euro 2 mopeds have been sold over 15 years now, the Dutch Euro 2 moped fleet shows a wide variety in mileage, age and vehicle technology.

Improve air quality and reduce negative impact on health
Dutch cities want to reduce the negative impact of mopeds and therefore consider various policy measures like environmental zones for mopeds. To quantify the effects of the various policy measures, detailed emission factors of the different moped types of the Dutch moped fleet are required. Dutch emission factors for the various moped types are available, however, these factors are based on emission measurements of a limited number of mopeds. Comprehensive surveys on the emissions of powered two-wheelers, particularly on mopeds, are scarce. Therefore, the ministry of Infrastructure and Water, and the cities of Nijmegen, Rotterdam, Amsterdam and Den Haag requested additional emission measurements to provide a sound basis for validating and refining the existing Dutch moped emission factors.

1.2 Aim and approach

The aim of this research is to determine moped emissions performance of a substantial set of vehicles with a variety of characteristics. The impact of the engine speed limiters, if present, on emissions and fuel consumption was investigated as well. The results of this study must provide a sound basis on which the existing moped emission factors can be validated and, if necessary, be refined.

A wide range of common vehicle types, representative for the Dutch moped fleet was selected for the testing program. Ranging from Euro 2 to Euro 3, 2-stroke to 4-stroke, new and in-use vehicles and fuel injection to carburetor. The vehicles were all subjected to two tests on a chassis dynamometer.

The testing program was designed in such a way that the effects of the following aspects on emissions could be assessed:

- Different engine technologies
  - 2-stroke and4 stroke;
  - Carburetor and electronic fuel injection;
- Cold start;
- 25 km/h versus 45 km/h construction speed;
- Mileage.

1.3 Structure of the report

In Chapter 2 the method of the test program is described. Also, the test cycle and vehicle selection are explained. Chapter 3 gives an overview and analysis of the test results. In Chapter 4 the current official Dutch emissions factors are shown and related to the measurement results collected in this study. In Chapter 5 the results are briefly discussed. The conclusion of this study is presented in Chapter 6.

2 Method

In this chapter the selection criteria for the test vehicles are explained and an overview of the selected vehicles is presented. Furthermore, the measurement program is explained.

2.1 Tested vehicles

In this study the aim was to set up a comprehensive testing program with a wide variety of mopeds. Therefore, the moped selection is based on:
- Representativeness for the Dutch moped fleet (make / model / Euro class).
- 25 km/h versus 45 km/h construction speed;
- Powertrain technologies such as 2-stroke engines, 4-stroke engines and electronic fuel injection;
- Mileage and origin: new from dealer and used from dealer;
- Budget and higher segment mopeds.

The selected mopeds can be found in Table 4. As shown in Table 4 most of the selected mopeds are Euro 2 mopeds. These mopeds represent the most frequently used Dutch mopeds (Verbeek, 2015 & Eijk, 2015). However, to select more advanced engine and emission reduction technologies, a Euro 3 model was selected as well.

Table 4 : Moped selection for this test program.

Engine type	**Construction speed**	**Euro class**	**Veh ID**	**Make / type**	**Odometer**	**Year**	**Power**	**Empty mass**
-	*[km/h]*	-	*[#]*	-	*[km]*	*[yyyy]*	*[kW]*	*[kg]*
2-stroke	25 km/h	Euro 2	1	Peugeot Fox[2]	4866	2005	0,84	57
2-stroke	25 km/h	Euro 2	2	Tomos Quadro[2]	12322	2005	0,95	55
2-stroke	45 km/h	Euro 2	3	Yamaha Aerox	11000	2013	2,4	92
2-stroke	45 km/h	Euro 2	4	Kymco Agility	7905	2014	2,5	109
4-stroke	25 km/h	Euro 2	5	Piaggio Vespa	250	2017	1,7	109
4-stroke	25 km/h	Euro 2	6	Kymco Agility	8640	2014	2,2	92
4-stroke	45 km/h	Euro 2	7	Piaggio Zip	250	2017	2,6	89
4-stroke	45 km/h	Euro 2	8	Piaggio Zip	3500	2015	2,6	89
4-stroke	45 km/h	Euro 2	9	La Souris	6500	2015	2,6	79
4-stroke	45 km/h	Euro 2	10	Peugeot Vivacity	24000	2011	2,8	95
4-stroke	45 km/h	Euro 2	11	Honda NSC*	4014	2014	2,5	101
4-stroke	45 km/h	Euro 2	12	Baotian Rebel	3750	2013	2,6	88
4-stroke	45 km/h	Euro 3	13	Piaggio Liberty*	250	2017	2,4	106
4-stroke	45 km/h	Euro 3	14	Piaggio Liberty*	2633	2016	2,4	106
4-stroke	45 km/h	Euro 3	15	Piaggio Liberty*	500	2017	2,4	106

* Mopeds with electronic fuel injection systems instead of carburetor

[2] For the Peugeot Fox and the Tomos Quadro it is uncertain if these are Euro 2 mopeds. According to the Dutch registration authority, the RDW, the date of first admission is 31-08-2005. When the moped registration became the responsibility of the RDW, mopeds with a construction year of 2005 or older were registered with a date of first admission of 2005. However, the emission levels of these mopeds are comparable to the other 2-stroke Euro 2 mopeds.

The mopeds tested in this program, were obtained via multiple official moped dealers. Before the start of the program, the condition of all vehicles was inspected. According to the moped dealers, the original anti-pollution components in the exhaust system of these vehicles were still present and the maximum vehicle speed was not modified. Some of the selected mopeds were completely new. At the start of the program these mopeds were driven for at least 250 km before the emission tests were performed, as prescribed by the European test procedure.

2.2 Test program

The mopeds were tested using the official ECE-R47 test cycle, the cycle that is also used during type-approval (Directive 97/24/EC), as shown in Figure 4. The test cycle consists of eight times the same elementary cycle, each of which consists of seven phases (Table 5). During the second phase of the test, the mopeds accelerates with full throttle operation up to the maximum speed. This is considered to be fairly representative for urban driving of mopeds. For the official Euro 2 test procedure, only the emissions of the warm test phase must be sampled, the warm test phase consists of the last four sub cycles. The emissions emitted during the cold test phase, consisting of the first four sub cycles, are excluded in the Euro 2 procedure. For the official Euro 3 test procedure the emissions of both the cold and the warm test phase are sampled. However, the cold and warm test phases are weighted for respectively 30% and 70% in the final result.

In this test program, the emissions of both Euro 2 and Euro 3 mopeds have been collected during the complete cycle. This is necessary to gain insight in the emission behaviour and allows to compare the results of the Euro 2 and Euro 3 mopeds. The program was set-up to determine emission performance of mopeds in the Dutch fleet.

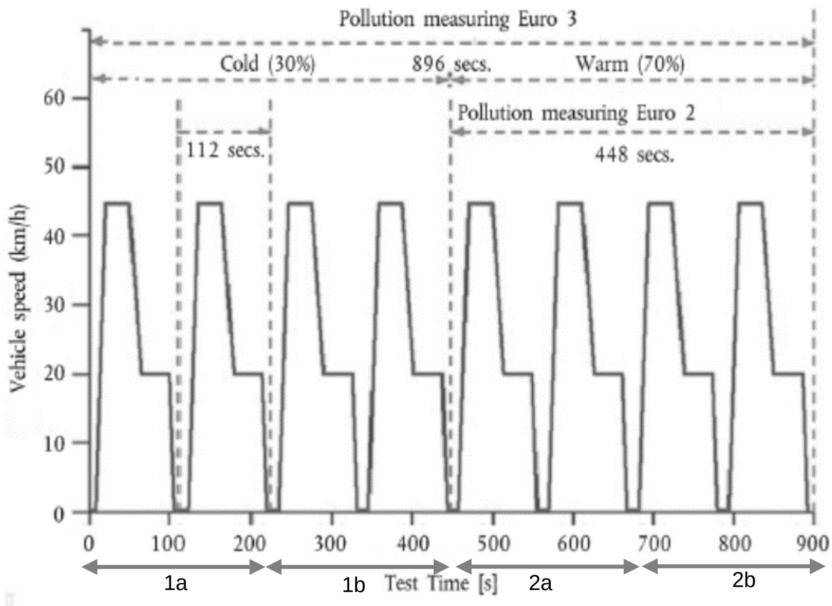


Figure 4: ECE-R47 test cycle from Directive 97/24/EC

Table 5: Official phases and characteristics of the ECE-R47 test cycle.

Phase number	**Operation**	**Acceleration (m/s2)**	**Speed (km/h)**	**Duration (s)**	**Cumulative time (s)**
1	Idling	-	-	8	8
2	Acceleration	Full throttle	0 to max speed	57	-
3	Steady speed	Full throttle	max speed		-
4	Deceleration	-0,56	max speed to-20		65
5	Steady speed	-	20	36	101
6	Deceleration	-0,93	20-0	6	107
7	Idling	-	-	5	112

In the test program the ECE-R47 was driven twice. Parts of both tests were kept the same, to be able to determine the reproducibility of the tests. In other parts of the tests conditions were changed to determine the impact of these changes on the emissions.

To investigate the effect of the cold start on emissions and the effect of maximum speed driving and the emission sampling was divided in three parts per test. Moreover, in some parts of the test, the official driver instructions as shown in Table 5 were adjusted for this measurement program to collect detailed information of the emission performance and fuel consumption at maximum speed driving. The cold start performance is also useful to assess the performance of the catalyst. The maximum speed driving is relevant as this may have a significant effect on the fuel consumption (Hensema, van Mensch, Vermeulen, 2013). To make a comparison with the official emission limits, the warm test phase of test 1 is executed in accordance with the legislation. The test programme was different for the Euro3 mopeds, as for Euro 3 mopeds the emissions of both the cold and the warm test phase are part of the official test procedure. The adjusted emission sampling and driver instructions are summarized below and can be found in Annex A, for each moped individually.

Table 6: Test programme

<table>
<tr><th></th><th></th><th colspan="2">Test 1</th><th rowspan="2">Purpose of test</th><th colspan="3">Test 2</th><th rowspan="2">Purpose of test</th></tr>
<tr><th></th><th></th><th>Cold test phase</th><th>Warm test phase</th><th>Cold test phase</th><th colspan="2">Warm test phase</th></tr>
<tr><td rowspan="2">Euro 2 mopeds</td><td>Emission sampling</td><td>Sampling divided in two sub phases</td><td>Sampled as one phase</td><td rowspan="2">Effect of cold start can be assessed in detail during the cold phase. The warm phase is executed in accordance with the legislation.</td><td>Sampled as one phase</td><td colspan="2">Sampling divided in two sub phases</td><td rowspan="2">Effect of maximum speed driving can be assessed during the warm test phase. The cold phase can be compared with the first test</td></tr>
<tr><td>Driver instruction</td><td>Full throttle</td><td>Maximum allowed speed: 25 or 45 km/h</td><td>Full throttle</td><td>Maximum allowed speed: 25 or 45 km/h</td><td>Full throttle</td></tr>
<tr><td rowspan="2">Euro 3 mopeds</td><td>Emission sampling</td><td>Sampling divided in two sub phases</td><td>Sampled as one phase</td><td rowspan="2">Effect of cold start can be assessed in detail during the cold phase. The complete cycle is executed in accordance with the legislation.</td><td>Sampling divided in two sub phases</td><td colspan="2">Sampled as one phase</td><td rowspan="2">Effect of cold start can be assessed in detail during the cold phase. The effect of maximum speed driving can be assessed by comparing the first and second test.</td></tr>
<tr><td>Driver instruction</td><td>Maximum allowed speed: 25 or 45 km/h</td><td>Maximum allowed speed: 25 or 45 km/h</td><td>Full throttle</td><td colspan="2">Full throttle</td></tr>
</table>

2.3 Emission measuring methods

All emission tests were performed on a chassis dynamometer at the University of Applied Sciences in Biel/Bienne (Switzerland). This university is very experienced in measuring powered two-wheeler emissions. The laboratory is certified to perform official type approval tests according to the European emission regulations.
The following regulated emissions were measured: CO (carbon monoxide), HC (hydrocarbons) and +NO_x (nitrogen oxides). Additionally, CO_2 (carbon dioxide), PM (particulate matter) and PN (particle number) were measured. Table 7 gives an overview of the measuring methods used in Biel/Bienne.

Table 7: Measuring methods

Emission component	**Method**
CO	NDIR (Non-Dispersive Infrared)
THC	H-FID (Hydrogen Flame Ionization Detector)
CH4	FID (Flame Ionization Detector)
NOx	CLD (Chemi-Luminescence Detector)
CO2	NDIR (Non-Dispersive Infrared)
PM	Gravimetric
PN	CPC (Condensation Particle Counter) with VPR (Volatile Particle Remover)

2.4 Data analyses

Like the official type approval procedure, the exhaust gasses are collected in bags. For this study three bags were used for the emission sampling as described in Table 6. The concentration of the components in the bags are analysed after the test. The total emission of each component is calculated from the measured concentrations, exhaust mass flow and driven distance. The presented final emission results in grams per kilometre are an average of all three bags.

3 Results

In this chapter the measurement results of the fifteen mopeds are presented.

3.1 Measurement results

In the program the mopeds were driven twice over a full ECE-R47 cycle. Table 8 shows the average results for CO, THC, NO_x, CO_2, PM and PN emissions. Figure 5 displays the individual emission results of the two tests. In the table, HC and NO_x emissions are also presented as a combined HC+NO_x value, to allow a comparison with the emission limit values as defined in the European emission standards. Although PN and PM emissions are not regulated for Euro 2 and Euro 3 mopeds, PM will be regulated for mopeds with direct fuel injection from Euro 5 on, particle emissions are investigated in this program as well.

Table 8 and Figure 5 clearly show that the results per emission constituent vary significantly per vehicle. This is not only the case for the pollutant emissions, but for the CO_2 emissions as well. In general, it is shown that 2-stroke mopeds have significant higher PM and HC emissions compared to 4-stroke mopeds. Mopeds with an electronic fuel injection system perform better on CO, THC and PN than the mopeds with a carburetor. On the contrary, the level of NO_x emissions for the 4-stroke mopeds with electronic fuel injection, especially the Euro 3 variants, are significantly higher than the other mopeds.

Table 8: Average results of two tests.

Engine type	**Speed**	**Euro Class**	**Vehicle ID**	**Make / type**	**CO**	**THC**	**NO_x**	**HC + NO_x**	**PM**	**PN**	**CO_2**	**Fuel con-sumption**
	km/h		#	-	*g/km*	*g/km*	*g/km*	*g/km*	*mg/km*	*#/km*	*g/km*	*L/100 km*
2-stroke	25 km/h	Euro 2	1	Peugeot Fox	4.11	3.95	0.04	3.99	242,5	1.48E+13	25.24	1,87
			2	Tomos Quadro	10.46	4.82	0.01	4.83	86,6	1.20E+13	18.71	2,14
	45 km/h		3	Yamaha Aerox	15.32	3.48	0.01	3.48	57,1	3.38E+13	58.24	3,95
			4	Kymco Agility	6.96	10.11	0.22	10.32	261,9	4.66E+13	33.41	3,24
4-stroke	25 km/h		5	Piaggio Vespa	7.49	2.04	0.10	2.14	6,3	3.87E+12	61.38	3,37
			6	Kymco Agility	10.59	0.52	0.06	0.58	4,0	3.10E+12	45.15	2,69
	45 km/h		7	Piaggio Zip	4.66	0.86	0.22	1.08	2,9	3.06E+12	39.64	2,10
			8	Piaggio Zip	6.34	0.90	0.13	1.03	12,9	4.19E+12	36.75	2,10
			9	La Souris	13.04	1.19	0.15	1.34	4,6	3.42E+12	35.79	2,54
			10	Peugeot Vivacity	20.32	1.55	0.08	1.63	9,0	2.93E+12	36.74	3,12
			11	Honda NSC*	0.44	0.36	0.26	0.63	1,9	1.00E+12	41.83	1,85
			12	Baotian Rebel	8.33	0.64	0.19	0.82	10,1	5.90E+12	35.19	2,13
		Euro 3	13	Piaggio Liberty*	1.81	0.92	0.32	1.24	5,9	2.62E+12	43.90	2,10
			14	Piaggio Liberty*	2.02	1.14	0.42	1.56	7,8	1.55E+12	45.53	2,22
			15	Piaggio Liberty*	2.05	1.02	0.35	1.37	5,5	2.87E+12	43.01	2,10

* Mopeds with electronic fuel injection systems instead of carburetor

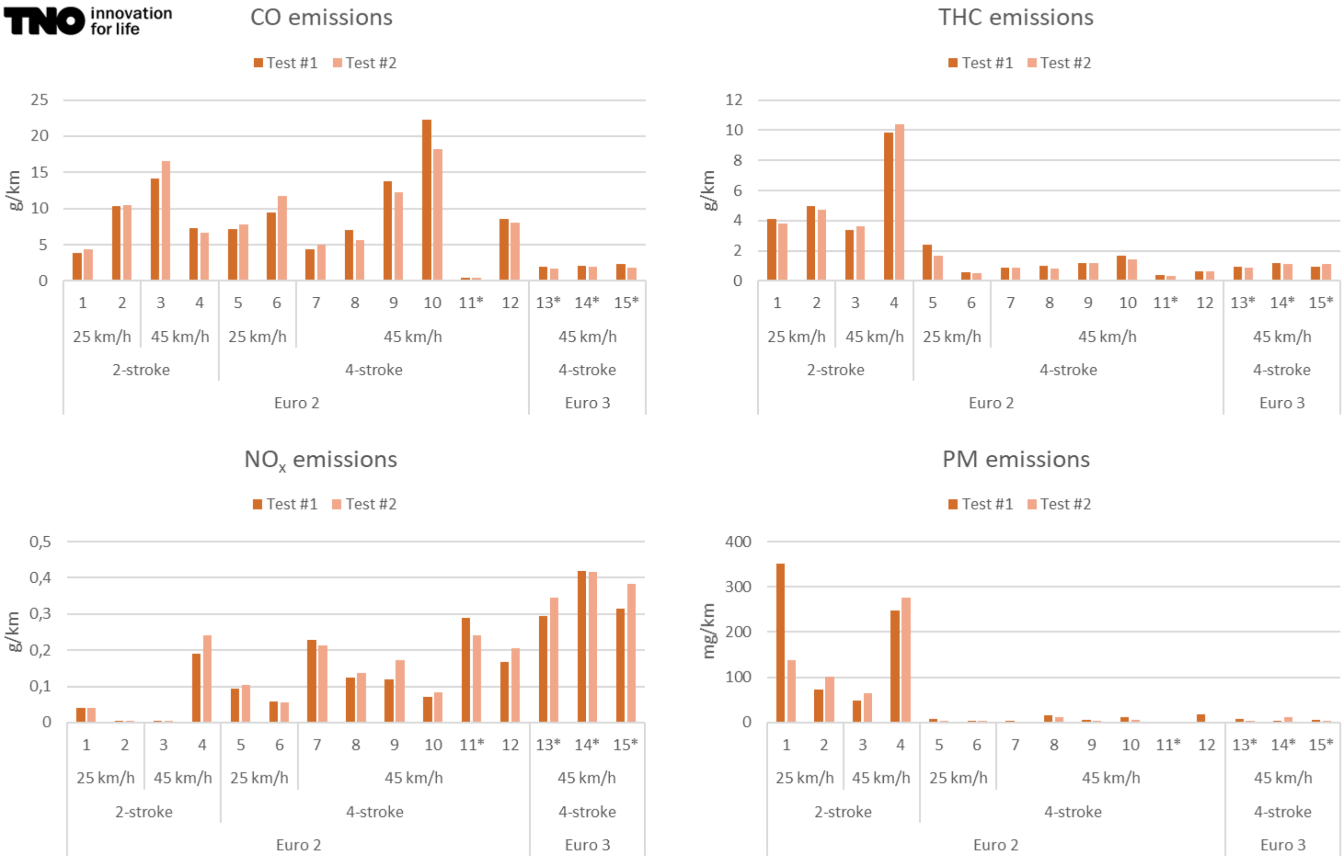


Figure 5: Individual emission results of the two performed tests. The numbers below the x-axis correspond with the vehicle ID as mentioned in Table 8. The ID's indicated with the '*' are mopeds with electronic fuel injection.

Figure 5 shows the results of each test separately. The driver instructions for the first and second test differed. Nevertheless, the emission levels of test 1 and test 2 are comparable. To make a proper assessment of the reproducibility of the test results, the cold test phase of test 1 and test 2 are compared as well since the cold test phase of both tests is performed in a similar way. This comparison is shown in Appendix B. The results show a good reproducibility which gives confidence in stable test results.

3.1.1 Comparison of the emission results to the type-approval standards

In this test program the official ECE-R47 test cycle is used for emission testing. However, in some parts of the test, the driver instructions differ from the official test procedure. Moreover, the cold start is included for Euro 2 vehicles which make most of the presented results in this report not comparable with the official emission limits as during type approval only the second (warm) test phase of the test is considered. In this paragraph the results of the first test are shown which is executed in a similar way as during type approval. For the Euro 2 vehicles only, the warm test phase is considered for the measured emissions. For Euro 3 vehicles both the cold and warm test phase are considered. However, the cold test phase is weighted for 30% and the warm phase for 70%, as shown in Figure 4. This is in accordance with the European directive 97/24/EC. It should, however, be noted that most of the vehicles were in-service, while mopeds during type approval only have driven a limited amount of kilometres. Furthermore, some details in the test preparation deviated from the official type approval procedure. For example, the procedures for preconditioning and soaking of the vehicle was not in accordance with the official procedure and market fuel was used rather than reference fuel.

The THC + NO_x and CO emissions are illustrated in Figure 6. The emissions of one Euro 2 moped were below the Euro 2 emission limits. This is remarkable, because this moped with a 4-stroke engine and electronic fuel injection the moped had a mileage of over 4.000 km. In contrast, two other new Euro 2 mopeds with a 4-stroke engine show emission results well above the emission limit value for CO. One of these two mopeds also showed THC + NO_x emissions well above the limit value due to high THC emissions. The Euro 3 moped has for all three vehicles for CO and for one vehicle for THC+NO_x emissions slightly higher than the limit value due to higher emissions in the cold phase.

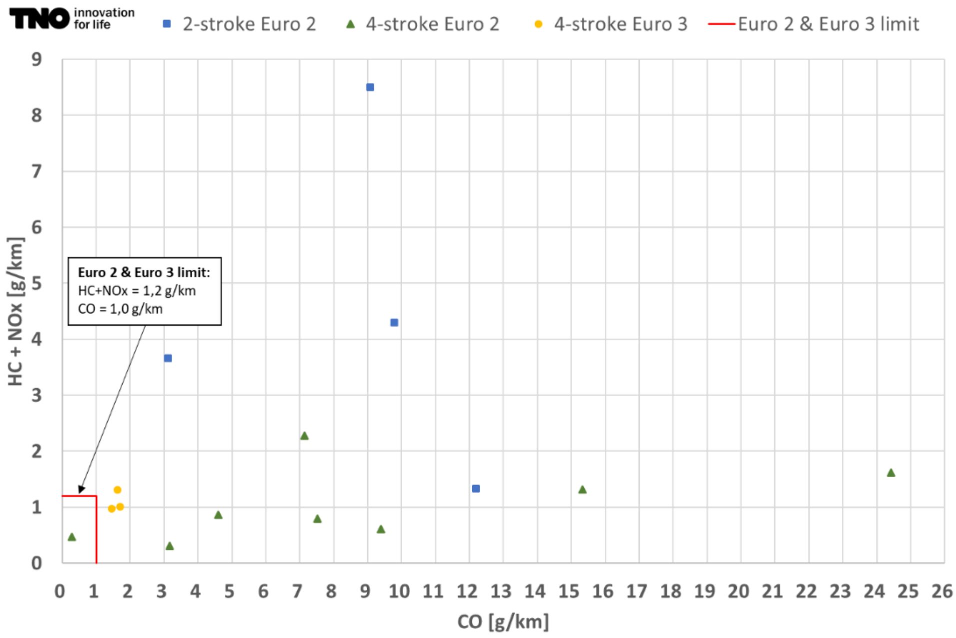


Figure 6: Emission performance of fifteen mopeds as measured in accordance with the R47 protocol.

3.2 2-stroke versus 4-stroke

The bars in Figure 7 show that, although the results vary significantly, on average 2-stroke mopeds emit approximately 25 times the amount of PM emissions of an average 4-stroke moped. The average 4-stroke PM emissions of approximately 6 mg/km are relatively low and very close to the future Euro 5 PM emission limit for mopeds. The average HC emissions of 2-stroke mopeds are nearly 5 times higher than the average 4-stroke results. In contrast to the HC and PM emissions, the NOx emissions of 4-stroke mopeds are approximately 3 times higher compared to the 2-stroke mopeds.

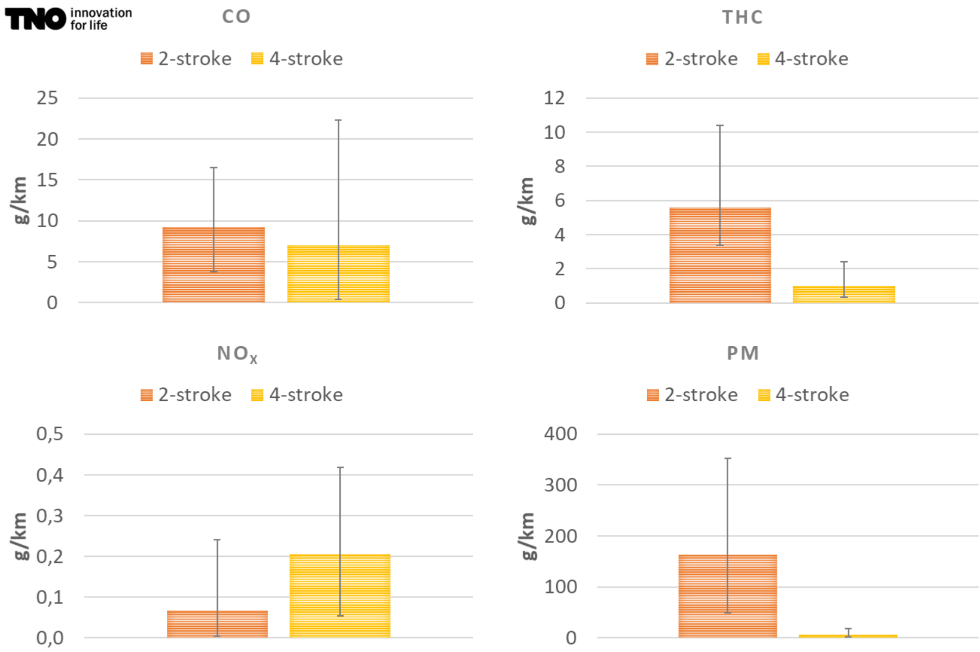


Figure 7: Average emissions of all tested 2-stroke & 4-stroke mopeds. The bandwidth indicates the minimum and maximum emission result of a specific moped.

3.3 Effects of mileage and cold start

Mileage

Figure 8 shows the CO emission results against mileage of all tested mopeds. Mopeds which were new and only driven for 250 kilometres already show CO emissions over 4 g/km. Figure 9 shows HC results against mileage of all mopeds. The HC emissions of 4-stroke mopeds are not clearly depending on vehicle mileage. For the tested 2-stroke mopeds no clear effect on vehicle mileage can be found. All tested Euro 3 mopeds perform regardless of the mileage in a similar way for HC and CO (Figure 8 and 9). The Euro 2 moped equipped with electronic fuel injection and a mileage of 4.000 km also still shows low HC and CO emissions. The durability of the mopeds equipped with electronic fuel injection seems to be better than the durability of mopeds with carburetors tested in this study.
Overall the impact of mileage on emissions is limited in the case of HC emissions, but substantial in the case of CO emissions.

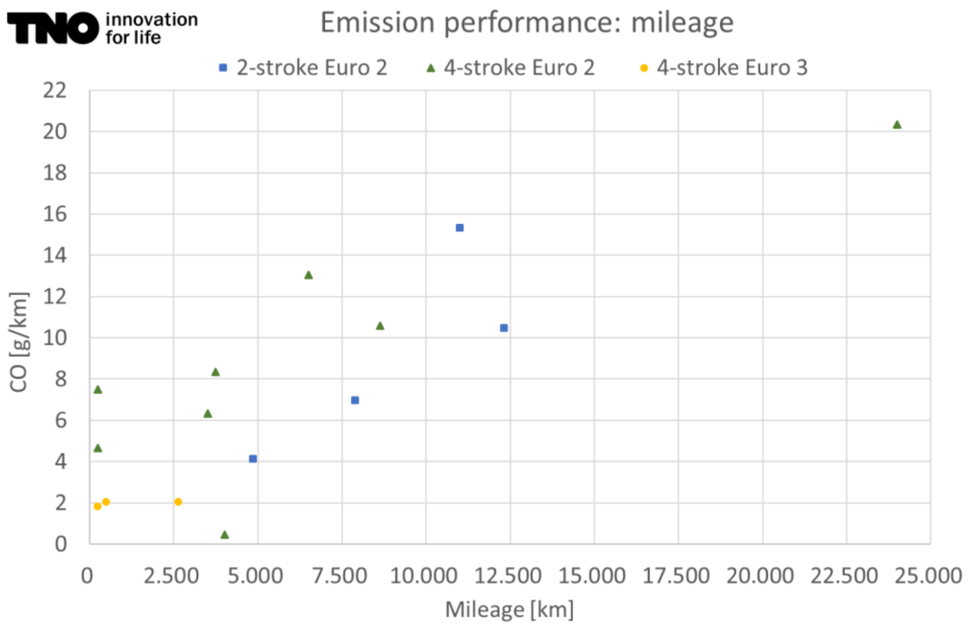


Figure 8: CO emission performance as a function of mileage.

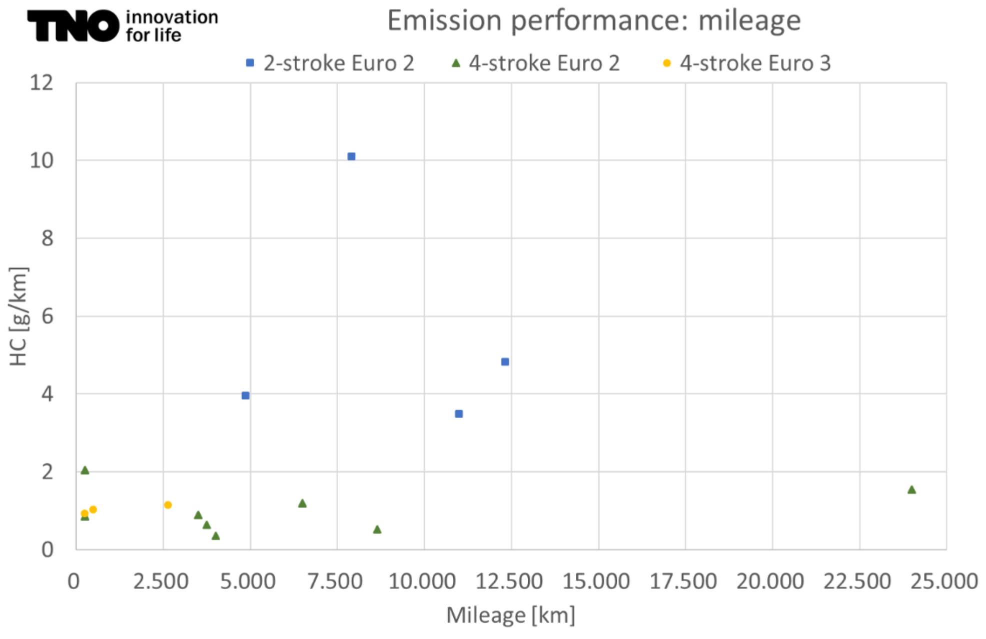


Figure 9: HC emission performance as a function of mileage.

Cold start emissions
In this test program the ECE-R47 is divided in three phases per test. As described in chapter 2, the emissions are measured over each phase separately. To check if the emission control system is still functional, the emission results measured during the cold test phase were divided in two parts. If the catalyst is functioning well, the emissions should decrease after the second part of the cold test phase.

In European legislation the first four of the in total eight sub-cycles of ECE-R47 test cycle are the cold start part. In this program the same approach is used to determine cold start emissions.

The figure below shows the emission performance during the cold test phase divided in part 1 and 2. Some mopeds do not show a decrease of CO while they do show a decrease on HC. Only a few mopeds show a decrease of CO emissions in part 2 of the cold test phase. Seven mopeds even have an increase of CO emissions in the second part of the test. This is remarkable because with a proper functioning 2-way catalyst system one would expect high emissions during the first cold part of the test and a reduction of both HC and CO emissions during the second part of the test. All mopeds equipped with electronic fuel injection show decreasing CO and HC emissions during the warm up of the engine and exhaust system. This indicates a proper functioning catalyst.

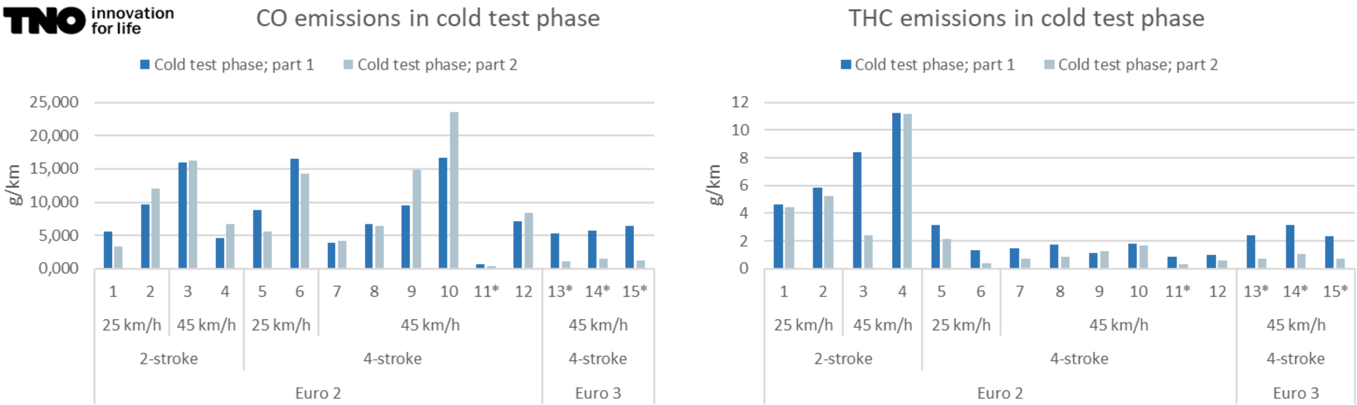


Figure 10: Emissions performance during a cold start in an unofficial ECE-R47 test cycle.

3.4 Fuel consumption and the effect of applied speed limiters on fuel consumption

Figure 11 shows the measurement results for fuel consumption of the two tests. The figure clearly shows that the fuel consumption varies significantly per moped.

The 2-stroke 25 km/h mopeds show the lowest fuel consumption. Often, 25 km/h mopeds use the same, or a comparable engine as the 45 km/h version of the same make and model, However, the tested in 2-stroke 25 km/h mopeds are a different type of moped. They are low powered and have a low vehicle mass, as can be seen in Table 4 in the chapter 2.

In contrast, the 2-stroke 45 km/h mopeds show a very high fuel consumption. There are passenger cars with a comparable fuel consumption. The tested 4-stroke 25 km/h mopeds show these kinds of high levels for fuel consumption as well. The fuel consumption of these 25 km/h versions are higher than the fuel consumption of most 4-stroke 45 km/h mopeds. In earlier studies, the high fuel consumption of 25 km/h 4-stroke mopeds were the result of inefficient speed limiters (Hensema et al., 2013).

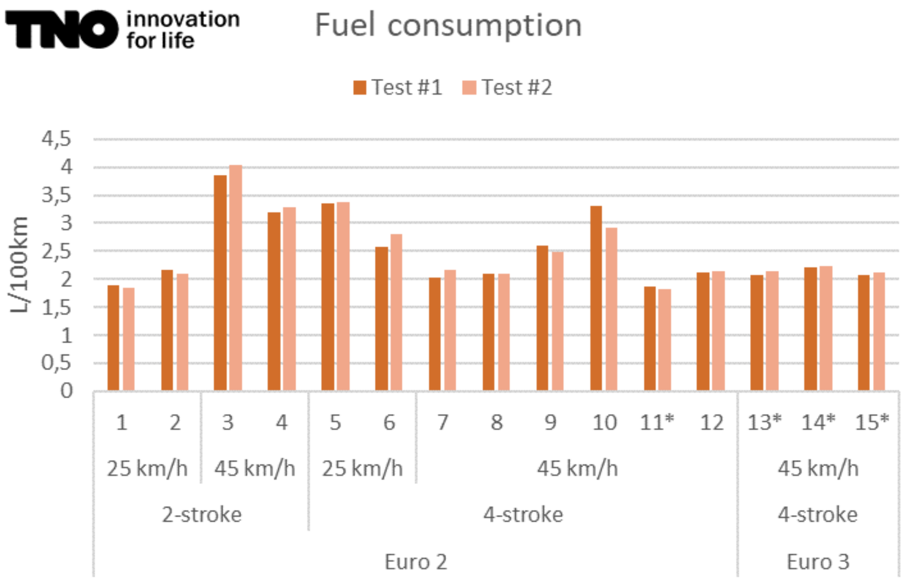


Figure 11: Individual fuel consumption results of the two performed tests. The numbers below the x-axis correspond with the vehicle ID as mentioned in Table 8. The ID's indicated with the '*' are mopeds with electronic fuel injection.

The effect of engine speed limiters

In earlier studies the effect of speed limiters on emissions and fuel consumption was investigated extensively (Hensema et al., 2013]). Commonly applied speed limiters for mopeds are 'engine speed limiters' (often applied for vehicles which use a carburetor for the fuel supply) and 'variomatic limiters' (transmission ratio limiters). Both types of speed limiters have a negative effect on fuel consumption (Hensema et al., 2013). The 'engine speed limiter' causes the largest negative effect in that study. The engine speed limiter delays the ignition timing for the combustion to restrict the engine speed. By doing so, a large part of the fuel is partially combusted not delivering engine power, resulting in a high fuel consumption. By driving only just below the limited speed of the vehicle, the negative effect of the engine speed limiter reduced, even to zero (Hensema et al., 2013).

In this study a part of the measurement program was aimed to investigate the impact of the engine speed limiters, if present, on emissions and fuel consumption. As described in chapter 2, the warm test phase of the R47 was divided in two sub-phases. In the first sub-phase the moped drove 2 – 3 km/h below its maximum speed. It was assumed that the engine speed limiter, if present, would not lead to a significant increase of emissions at this speed as it was assumed that the ignition delay is not enabled yet. In the second sub-phase, the moped was driven at its maximum speed. It should, however, be noted that the steady speed driving at maximum speed is only a part of the driven R47 cycle. Therefore, any possible negative effects due to the speed limiter occur only in some parts of the R47 cycle. The effect of the speed limiter in real-world conditions depends on the share of driving at maximum speed.

In Figure 12 the impact on fuel consumption of driving at maximum speed is shown. The fuel consumption is calculated with the carbon balance method. This means that the fuel consumption is based on the CO, THC and CO_2 emissions.
As shown in Figure 12, the impact of driving at maximum speed on the fuel consumption strongly varies for each moped. The negative effects of the speed limiter are noticeable when the increase of fuel consumption is disproportional with the increase of vehicle speed. The fuel consumption of vehicles 6, 9 and 10 is strongly increased, this might be the result of an engine speed limiter. It seems that especially 4-stroke mopeds which use a carburetor for the fuel supply are affected in a negative way. It was expected that the effect would be especially noticeable at the 25 km/h 4-stroke mopeds. For vehicle 6 there is a clear effect at maximum speed. However, for vehicle 5 no effect is displayed in the figure below. This may be the result of an inconsistency in the test execution. Vehicle 6 was tested at 3 km/h below its maximum speed whereas vehicle 5 was tested at 1 km/h below its maximum speed. This 1 km/h difference in speed is most likely not sufficient to disable the ignition delay. Another possible explanation would be that another kind of speed limiter is applied. Either way, the fuel consumption of vehicle 5 is second highest of all vehicles which makes it likely to assume that an inefficient speed limitation is applied.

The tested 2-stroke mopeds and the mopeds with electronic fuel injection do not show a clear negative effect on fuel consumption. More efficient types of speed limiters may be used in these mopeds.

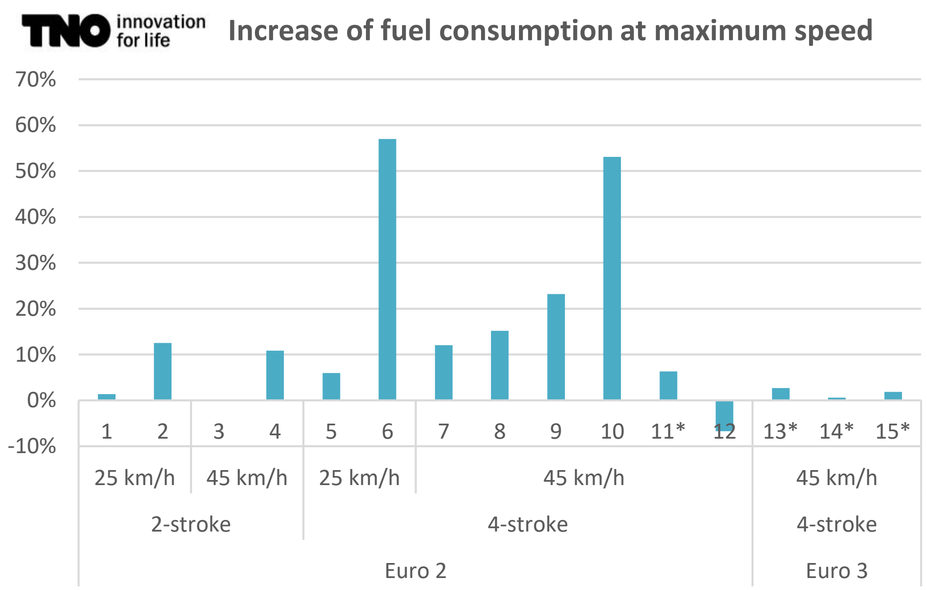


Figure 12: Effects of driving at maximum speed versus driving 2 – 3 km/h below maximum speed on the fuel consumption.

4 Test results and emission factors

Table 9 shows the current (2017) official Dutch emission factors for various, non-tampered, moped types (Dröge, van Zyl, van Mensch, Ligterin & Kadijk, 2014). These emission factors are based on test results of a limited amount of test vehicles. The factors in table 5 represent average emissions in grams per kilometre for average driving style and trip length for an average moped of the classes as mentioned in table 5. In the past, TNO did perform several emission measurement programs. To update the emission factors and to investigate the influence of moped modifications on emissions, TNO performed an additional test program in 2013 (Hensema et al, 2013). The 2013 program was based on two moped models only. The current emission factors for the Euro 2 mopeds are mainly based on the results of the 2013 program.

Table 9: Current Dutch emissions factors of standard mopeds (Dröge et al., 2014).

Moped type		Euro-Class	CO [g/km]	THC [g/km]	NO_x [g/km]	THC + NO_x [g/km]	PM_{10} (exhaust) [g/km]
2-stroke	25 km/h	Euro 2	5,63	5,27	0,12	5,39	0,07
	45 km/h	Euro 2	4,79	4,38	0,10	4,47	0,06
4-stroke	25 km/h	Euro 2	24,1	1,75	0,04	1,79	0,01
	45 km/h	Euro 2	18,4	1,23	0,04	1,27	0,01

The test results presented in this study, covering 15 mopeds of different make, model and technology are suitable to validate and, if necessary, to refine the current emission factors. The test results of this study are considered to be representative for on-road emission behaviour of non-tampered mopeds with an original speed limiter.

The test results as presented in table 8 in chapter 3.1 in this report are aggregated to average results per moped type.

Table 10: Average emission results of tested moped classes

Engine type	**Speed**	**Euro class**	**CO** *g/km*	**THC** *g/km*	**NOx** *g/km*	**HC+NOx** *g/km*	**PM** *g/km*	**PN** *#/km*
2-stroke	25 km/h	Euro 2	7.29	4.39	0.02	4.41	0.16	1.3E+13
	45 km/h		11.14	6.79	0.11	6.90	0.16	4.0E+13
4-stroke	25 km/h		9.04	1.28	0.08	1.36	0.01	3.5E+12
	45 km/h		8.86	0.92	0.17	1.09	0.01	3.4E+12
		Euro 3	1.96	1.03	0.36	1.39	0.01	2.3E+12

Although the emission measurement results presented in Table 10 are measured under average driving behaviour, they cannot directly be compared to the average Dutch emission factors, because of the difference in average Dutch trip length and the influence of the cold start emissions, the test results allow a first indicative comparison of the current Dutch moped emission factors and the test results.

CO
The CO test results for 2-stroke and 4-stroke Euro 2 mopeds are quite similar. The current Dutch CO emission factors indicate lower 2-stroke and higher 4-stroke emissions than the measurement results. This indicates that the emission factors probably overestimate the CO emissions of 4-stroke Euro 2 mopeds and underestimate CO emissions of 2-stroke mopeds. It must be noted that the different mopeds tested in this program do show a large variation in CO test results (see table 8). The serious improvement with Euro 3 implies a need of a separate category in the emission factors.

HC
The HC emissions as measured in this program are quite similar to the Dutch emission factors. The HC emissions of 2-stroke Euro 2 mopeds in general are approximately 5 times higher than the 4 stroke Euro 2 HC emissions (45 km/h version). The average HC test results of the 2-stroke Euro 2, 45 km/h mopeds are approx. 50% higher than the Dutch emission factors for this moped type. This result is strongly influenced by one high emitting moped. The average HC test results of the 4-stroke Euro 2 mopeds (both 25 km/h and 45 km/h) are approximately 25% lower than the average Dutch emission factors.

NOx
The NO_x measurement results of 4-stroke Euro 2, 45 km/h mopeds are significantly higher than the NO_x emission factor. For 2-stroke Euro 2, 25 km/h mopeds the measurement results are lower than the emission factors. The relatively high NOx emissions for the Euro 3 mopeds support the need of Euro 3 emission factors.

PM_{10} / PN
The PM_{10} test results of 4-stroke mopeds are the same as the emission factors for PM_{10}. The PM_{10} test results of 2-stroke mopeds are higher than the emission factors. The PM_{10} and PN measurement results of the 4-stroke Euro 3 mopeds are comparable to the 4-stroke Euro 2 measurement results.

The measurement results of this study will be provided to the parties responsible for the Dutch national Emission Factors.

The comparison indicates that some emission factors of specific moped types might need some further analyses and refinement. For example, for 2-stroke mopeds, the PM_{10} and HC emission factors are lower than the emission test results collected in this study. For 4-stroke mopeds, the NOx emission factors are lower than the test results. Overall, the current Dutch emission seem to represent the Dutch moped fleet emissions reasonably well.

5 Discussion

Possible causes of the high emissions of Euro 2 mopeds
Very high CO and HC emissions are observed in this study, even from mopeds which were new. The only exception was the moped with electronic fuel injection technology. The cause of the high emissions of the Euro 2 mopeds is not investigated in this study. Possibly, the high emissions observed in this study are the result of fast degraded anti-pollution devices – even if vehicles have been driven for just 250 or 500 km -, as there are no durability requirements for the tested vehicles yet. Another possibility can be related to adjustments to the vehicles. In the study of Ntziachristos, Vonk, Papadopoulos & van Mensch (2017) it was discussed that based on discussions with several dealers of mopeds in the Netherlands, it is suspected that many new mopeds are adjusted by dealerships before the new moped is handed over to its first owner. The dealerships claim that they make this adjustment to deliver a vehicle to the client that meets the client expectations: a moped with a smooth-running engine that starts and drives well under all conditions. This adjustment often involves replacement of the fuel nozzle by a larger one, this applies to vehicles with an engine with a carburetor. According to the dealers, the client's expectations for drivability often cannot be met without the adjustments. In this study it is not investigated if the identified high emissions can be the related to adjustments made. Alternatively, ineffective Conformity of Production (CoP) can also be a possible cause.

Emissions of Euro 3 mopeds
The Euro 3 mopeds showed a better performance on CO and HC emissions. Also, the Euro 3 moped with a mileage of 2633 km showed comparable results as the Euro 3 mopeds with low mileages. The Euro 2 moped with electronic fuel injection and a mileage of more than 4.000 km also shows these lower emissions. Hence, the tested mopeds with electronic fuel injection show better performance on durability of the emission control system. Moreover, the Euro 3 vehicles did not show a negative effect on fuel consumption due to engine speed limitation. The same applies to the Euro 2 moped with electronic fuel injection.

In the past NO_x emissions of mopeds were never considered to be a relevant problem for air quality. Even though emission factors are comparable to those of petrol passenger cars, the number of vehicles and the mileage is much lower and accordingly the total emissions are much lower. However, the Euro 3 mopeds tested in this study show rather high NO_x emissions, in the range of real world emissions of Euro 6 diesel passenger cars. It is expected that the technology of Euro 4 mopeds will be based on the technology of the Euro 3 mopeds. Therefore, it is recommended to test several Euro 4 mopeds in near future to examine the Euro 4 NO_x emissions. The high NO_x emissions seem to be typical for mopeds with electronic fuel injection, as the other Euro 2 moped equipped with this technology has relatively high NO_x emissions as well.

From Euro 4 onwards, there will be separate NOx limits for mopeds: 170 and 60 mg/km for Euro 4 and Euro 5 respectively. The measured emissions of the Euro 3 mopeds range between 290 and 420 mg/km. This would justify adding Euro 3 mopeds as a separate category in the emission factors and the emission inventories.

Emission legislation

As mentioned in the introduction of this report the Euro 4 regulation for mopeds is implemented in 2017. This Euro 4 regulation contains more stringent emission limits. However, the emission limits are still less stringent than for Euro 6 passenger cars. In addition to Euro 3, the Euro 4 step has a comprehensive package of environmental tests, including durability requirements, a fuel permeability test and a crankcase emission test. The intention of the Euro 4 regulation was not only to force the introduction of new less emitting mopeds, but also to pay more attention to the emissions during their useful life. In 2020 the Euro 5 regulation will be implemented with emission limits comparable to those of Euro 6 passenger cars. Moreover, the WMTC, a new more dynamic test cycle, will be introduced for mopeds as well. It is expected that more advanced engines technologies are needed to comply with the Euro 4 and Euro 5 emission limits. Potentially this should secure a lower level of emissions during the useful life of a vehicle (Ntziachristos et al., 2017). A test program of early Euro 4 mopeds could be helpful to assess the impact of the introduction of new technologies on the emissions performance of future mopeds.

Post Euro 5

The measurement results as presented in this report clearly show the need to regulate and inspect emissions of in-use vehicles, as most emission results are high compared to the emission limit values. For Euro 4 and Euro 5 mopeds, engine and exhaust aftertreatment technology will be more advanced to realize the required low emission levels. It is important that these low emission levels are also ensured during the useful life of the vehicles in real world circumstances. In-Service-Conformity (ISC) and on-road tests are possible methods to monitor in-use and on-road emission levels of mopeds. By combining laboratory and on-road test procedures, the real-world emission performance of in-use vehicles could be thoroughly secured in the most representative way (Ntziachristos et al., 2017). This approach is already applied for passenger cars and heavy-duty vehicles emissions legislation.

6 Conclusions

In this study 15 mopeds were tested on a chassis dynamometer at the University of Applied Sciences in Biel/Bienne (Switzerland). The following regulated emissions were measured: CO (carbon monoxide), HC (hydrocarbons) and NO_x (nitrogen oxides). Additionally, CO_2 (carbon dioxide), PM (particulate matter) and PN (particle number) were measured.

The aim of this research is to determine moped emission performance of a substantial set of vehicles with a variety of different characteristics. The impact of cold start emissions and the impact of the engine speed limiters, if present, on emissions and fuel consumption were investigated as well. The results of this study must provide a sound basis on which the existing moped emission factors can be validated and, if necessary, be refined.

Emission results
In general, all tested *Euro 2* mopeds did show high emission levels.
Some of these mopeds were new.

- Even though the cold start emissions are included in the test results, the HC + NOx emissions of 4-stroke mopeds were in general close to the Euro 2 emission limits.
- However, the Euro 2 vehicles with a 2-stroke engine showed significantly higher HC + NOx emissions than the 4-stroke mopeds.
- The 2-stroke mopeds also emit on average 25 times more PM_{10} than 4-stroke mopeds.
- Relatively low CO emissions were measured for the 4-stroke Euro 3 mopeds.
- Remarkable was the relatively low fuel consumption of the tested 2-stroke mopeds of the 25 km/h category. These are mopeds with a low mass and a low engine power.
- One Euro 2 moped, a 4-stroke moped equipped with electronic fuel injection, and a mileage of more than 4000 km, did perform well on all emission constituents.

All three *Euro 3* mopeds of the same model tested in this study did perform in a very similar way. The Euro 3 mopeds performed quite well for most of the emission components and the results are hardly influenced by the vehicle mileage or engine speed limiter. Only for NOx, all three Euro 3 mopeds did show high emission levels, levels comparable to modern Euro 6 diesel passenger cars. It is expected that the technology of Euro 4 mopeds will be based on the technology of these Euro 3 mopeds. Therefore, it is recommended to test several Euro 4 mopeds in near future to examine the Euro 4 NO_x emissions

Emission factors
In general, the emission test results of this study show that the current Dutch average emission factors for the Euro 2 mopeds do represent the average emissions of the various Euro 2 moped types quite well. The results will be used to improve the reliability of the emission factors, but a first comparison with the test results shows that the overall picture will not change significantly.

Cold start
This study also investigated the effect of a cold start on emissions. A cold catalyst does not convert pollutants so during warm-up one expects to see a decrease in pollutants with a well-functioning catalyst. In this study, only few mopeds show decreased CO emissions during warm up, 7 of the 15 tested mopeds even show an increasing trend of the CO emissions during warm-up, indicating the poor functionality of the applied emission control devices. All mopeds equipped with electronic fuel injection show decreasing CO and HC emissions during the warm up of the engine and exhaust system. This indicates a proper functioning catalyst.

Future emission tests of mopeds
The high emission levels of the tested in-use vehicles show the need to regulate and inspect emissions of in-use vehicles. Following the regulation for passenger cars, and heavy-duty vehicles, it is recommended to perform both chassis dynamometer tests as well as on-road emission measurements from Euro 4 on. Euro 4 mopeds are expected to have more advanced engine- and exhaust gas aftertreatment technologies which make them more interesting to test in other conditions (real world) than in the laboratory.

7 References

Verbeek M.M.V. (2015), *Bijdrage van brommers aan de luchtkwaliteit in Amsterdam*, TNO 2015 R11435

Eijk, A.R.A, Stelwagen, U. (2015), *Samenstelling van het brommerpark in de gemeente Utrecht, brommer kentekenscan 2014*, TNO 2015 R10060

Hensema, A., Mensch, P. van, and Vermeulen, R. (2013), *Tail-pipe emissions and fuel consumption of standard and tampered mopeds,* 2013, TNO 2013 R10232

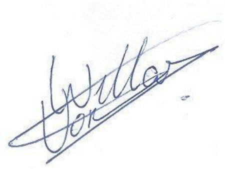
Dröge, R., van Zyl, P.S., van Mensch, P., Ligterink, N.E., Kadijk, G. (2014), *Update emission model for two-wheeled mopeds*, TNO 2014 R11088

Ntziachristos, L., Vonk , W., Papadopoulos, G., van Mensch, P., (2017). *Effect study of the environmental step Euro 5 for L-category vehicles*, TNO Report 2017 R10565, The Hague, Netherlands.

8 Signature

The Hague, 12 December 2017

TNO



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A Driver instructions for phase 3 in ECE R47

	Engine type	Construction speed		Make / type	Test 1		Test 2		
					Cold part	Warm part	Cold part	Warm part	
								Subcycle 1 and 2	Subcycle 3 and 4
		km/h		-					
1	2-stroke	25 km/h	Euro 2	Peugeot Fox	Full throttle	25 km/h	Full throttle	25 km/h	Full throttle
2	2-stroke	25 km/h	Euro 2	Tomos Quadro	Full throttle	25 km/h	Full throttle	25 km/h	Full throttle
3	2-stroke	45 km/h	Euro 2	Yamaha Aerox	Full throttle	45 km/h	Full throttle	45 km/h	Full throttle
4	2-stroke	45 km/h	Euro 2	Kymco Agility	Full throttle	45 km/h	Full throttle	45 km/h	Full throttle
5	4-stroke	25 km/h	Euro 2	Piaggio Vespa	Full throttle	25 km/h	Full throttle	25 km/h	Full throttle
6	4-stroke	25 km/h	Euro 2	Kymco Agility	Full throttle	25 km/h	Full throttle	25 km/h	Full throttle
7	4-stroke	45 km/h	Euro 2	Piaggio Zip	Full throttle	45 km/h	Full throttle	45 km/h	Full throttle
8	4-stroke	45 km/h	Euro 2	Piaggio Zip	Full throttle	45 km/h	Full throttle	45 km/h	Full throttle
9	4-stroke	45 km/h	Euro 2	La Souris	Full throttle	45 km/h	Full throttle	45 km/h	Full throttle
10	4-stroke	45 km/h	Euro 2	Peugeot Vivacity	Full throttle	45 km/h	Full throttle	45 km/h	Full throttle
11	4-stroke	45 km/h	Euro 2	Honda NSC	Full throttle	45 km/h	Full throttle	45 km/h	Full throttle
12	4-stroke	45 km/h	Euro 2	Baotian Rebel	Full throttle	45 km/h	Full throttle	45 km/h	Full throttle
13	4-stroke	45 km/h	Euro 3	Piaggio Liberty	45 km/h	45 km/h	Full throttle	Full throttle	Full throttle
14	4-stroke	45 km/h	Euro 3	Piaggio Liberty	45 km/h	45 km/h	Full throttle	Full throttle	Full throttle
15	4-stroke	45 km/h	Euro 3	Piaggio Liberty	45 km/h	45 km/h	Full throttle	Full throttle	Full throttle

B Reproducibility of the test results

Two tests are performed on each moped. This to ensure reproducibility of the test results and to gather additional information of cold start effects, influence of speed limiter etc. Both tests are driven under the same conditions during the first part of the test cycle. The second part of the cycle was driven slightly different to gain information on the before mentioned parameters. To make a proper assessment of the reproducibility of the test results, the first part of the test 1 and test 2 are compared. This comparison is shown in the figure below. The results show a good reproducibility which gives confidence in stable test results.

C Emission legislation for mopeds

In June 1999, multi-Directive 97/24/EC (Euro 1) introduced the first emission limits for mopeds. An additional stage of the legislation came into force in June 2002 (Euro 2). New Euro 3, 4 and 5 emission limits for mopeds have been agreed by Council and Parliament and will come into force from 2014 onwards. In Table 11 the consecutive standards are presented:

Table 11: European emission limits for mopeds

Stage and starting date	**Technical specifications**	**CO mg/km**	**HC mg/km**	**NO_x mg/km**	**HC+NO_x mg/km**	**PM mg/km**
Euro 1 (17/6/1999)	Mopeds	6000	-	-	3000	-
Euro 2 (17/6/2002)	Mopeds	1000	-	-	1200	-
Euro 3 (1/1/2014)	Two-wheel moped (max 45km/h)	1000[3]	-	-	1200[3]	-
Euro 4 (1/1/2017)	Two-wheel moped (max 45km/h)	1000	630	170	-	-
Euro 5 (1/1/2020)	Two-wheel moped (max 45km/h)	1000	100	60	-	4.5

[3] These seem to be the same limits as for Euro 2, but the difference is how the emission results are calculated. From Euro 3 on, the cold start is included in the emission results as well.