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TNO report

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Update emission model for two-wheeled mopeds

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Contents

1 Introduction

1.1 Background

In 2011, an emission model was developed which is used in the yearly national reporting of emissions of two-wheeled mopeds [TNO, 2011]. At the time no differentiation was made for different engines, speed limiters or configurations. Due to lack of more specific data, the model was simplified to only make a difference between the different Euro-classes 0, 1 and 2.

In 2013, TNO performed new measurements on Euro-2 mopeds [TNO, 2013]. These measurements give new insights in the effects of different parameters on vehicle emissions. It was determined that depending on the engine type, speed limiter type, configuration and test cycle emission factors differ largely. In order to determine representative emission factors for each Euro class, emission factors were calculated on an aggregated level.

1.2 Aim and approach

The aim of this study is to update the current emission model with the knowledge gained in the latest measurements. The updated model will allow for a more detailed overview of Euro-2 emission factors in relation to:

- the engine (2-stroke and 4-stroke);
- the speed limiter (25 km/h, 45 km/h);
- the configuration (standard, altered and tampered).

With the new insights of Euro-2 emission factors, Euro-1 and Euro-0 will be kept the same or respectively set equal to Euro-2 emission factors if Euro-2 emission factors are higher.

1.3 Scope

The here discussed emission factors focus on two-wheeled mopeds and in specific two different configurations. By European law, mopeds have an engine capacity smaller than 50cc which distinguishes them from motorcycles. In Dutch law, two configurations are allowed: the 25 km/h version and 45 km/h version. In practice, international manufacturers of mopeds produce the same vehicle for both categories with the same technical specifications. The only difference lies in the type of speed limiter which is applied, i.e. limiting the maximum speed of the vehicle to 25 km/h or 45 km/h.

1.4 Structure of the report

This report provides a short overview of the resulting new emission factors, the used measurement data and methodology used for deriving the emission factors. The report closes with the conclusions and recommendations.

2 Emission measurements and method for deriving emission factors

In this chapter, more detail is provided on the emission measurements that were used in order to determine emission factors. Furthermore, the method for calculating emission factors is further detailed.

2.1 Emission measurements

In 2013, emission measurements have been performed by TNO on two-wheeled Euro-2 mopeds [TNO, 2013]. The following variables were part of the testing program:

- the engine type (2-stroke and 4-stroke);
- the active speed limiter (25 km/h and 45 km/h);
- the actual configuration (standard, adjusted and tampered);
- the test cycle (official ECE-R47 test cycle, test cycle at max. allowed speed, test cycle at max. configuration speed).

The three different configurations were defined as follows:

- standard: a moped with the speed limiter in place;
- altered: a moped with the speed limiter removed;
- tampered: a moped with a tuned configuration.

2.2 Method for deriving detail emission factors

Emission factors were calculated for Euro-2 mopeds with the combination of the following parameter sets (see Table 1).

Table 1: Emission factors derived for the combination of following parameter sets.

Engine type	Speed limiter type	Configuration	Urban	Rural
4-stroke	25 km/h	Standard (S)	x	x
		Altered (A) – removed limiter	x	x
		Tampered (T) – tuned configuration	x	x
	45 km/h	Standard (S)	x	x
		Altered (A) – removed limiter	x	x
		Tampered (T) – tuned configuration	x	x
2-stroke	25 km/h	Standard (S)	x	x
		Altered (A) – removed limiter	x	x
		Tampered (T) – tuned configuration	x	x
	45 km/h	Standard (S)	x	x
		Altered (A) – removed limiter	x	x
		Tampered (T) – tuned configuration	x	x

For each configuration emission factors were determined for urban and rural driving behaviour. The emission factors for urban and rural driving were determined by following a weighing procedure described in next formulas:

$EF_u = ks/3 + R47;$
$EF_r = ks/6 + \mu; \quad \mu = (R47+MCS)/2;$

with ks being the emissions of a cold start, R47 the emission factor of a ECE-R47 test cycle and MCS being the emission factor of a test cycle at maximum configuration speed. For a standard configuration, the maximum speed is equal to the maximal allowed speed. For an adjusted and tampered configuration, the maximum speed is defined as the maximum speed achieved by the moped without speed limiter. The emission factors are effectively larger at higher speeds. For urban driving behaviour, it was assumed that a typical trip distance is 3 km, thus resulting in a cold start every 3 km. For rural driving behaviour, the average trip distance was assumed to be 6 km.

Limited measurement data was available for the speed limiter of 25 km/h, both for a 2-stroke as well as the 4-stroke engine. For that reason, the following assumptions were made:

- The emission factor of a tampered 4-stroke moped with a 25 km/h speed limiter is **equal to** the emission factor of a tampered 4-stroke moped with a 45 km/h speed limiter.
- The emission factor of a standard 2-stroke moped with a 25 km/h speed limiter is **40% higher than** the emission factor of a standard 2-stroke moped with a 45 km/h speed limiter.
- The emission factor of an altered 2-stroke moped with a 25 km/h speed limiter is **equal to** the emission factor of an altered 2-stroke moped with a 45 km/h speed limiter.
- The emission factor of a tampered 2-stroke moped with a 25 km/h speed limiter is **equal to** the emission factor of a tampered 2-stroke moped with a 45 km/h speed limiter.

2.3 Method for deriving aggregated emission factors

When calculating aggregated emission factors for mopeds, estimations are made on the expected share of different moped configurations.

Since altering or tampering mopeds is illegal, it is difficult to collect reliable data on the actual share of different configurations on the roads. However, several studies exist on the amount of mopeds that exceed speed limits in practice as well as the amount of mopeds that achieve higher speeds than specified in the type approval tests (see Table 2 to Table 5).

Table 2: Share of altered and tampered mopeds on the roller dynamometer in 2004, 2005 and 2007 [SWOV, 2009]. Data is based on approximately 15,000 measurements per year.

	2004	2005	2007
Share of altered or tampered mopeds on the roller dynamometer	31%	28%	22%

Table 3: Share of altered and tampered mopeds on the roads in 2011, 2012 and 2013 [AMS, 2013]. Data is based on roughly 250 survey replies per year.

	2011	2012	2013
Share of altered or tampered mopeds on the roads	26%	41%	42%

Table 4: Share of mopeds exceeding speed limits in 2011 [RWS, 2011]. Data is based on measurements performed on biking lanes.

	2011
Share of mopeds (type: 25 km/h) exceeding 35 km/h	40%
Share of mopeds (type: 25 km/h) exceeding 40 km/h	20%

Table 5: Share of mopeds exceeding speeds limits in 2010 and 2012 [FB, 2012]. Data is based on measurements performed on biking lanes.

	2010	2012
Share of mopeds (type: 25 km/h) exceeding 25 km/h	94%	97%
Share of mopeds (type: 25 km/h) exceeding 39 km/h	44%	34%

Study results from Table 2 and Table 3 show that throughout the years approximately 30% (in the latest years 40%) of the mopeds are altered or tampered. This also coincides roughly with the results shown in Table 4 and Table 5. It is assumed that in 20 to 30% of the cases, mopeds are altered and that in 10% of the cases mopeds are tampered. In conclusion the following percentages are assumed as a share in different moped configurations, see Table 6.

Table 6: Share of different speed limiters for mopeds type 25km/h and 45 km/h.

Speed limiter	25 km/h	45 km/h
Standard	60%	70%
Altered	30%	20%
Tampered	10%	10%

3 Emission factors for two-wheeled mopeds

In this chapter, the updated emission factors for two-wheeled mopeds are displayed and compared with emission factors derived in the previous emission model.

Detailed emission factors for Euro classes 0 to 2 are displayed for each engine type, speed limiter type and configuration, separately for urban and rural driving behaviour in sections 0 to 3.3.

Aggregated emission factors applying the assumptions made in the previous chapter are showed in section 3.4. In section 3.5, the aggregated emission factors of the updated emission model are compared with the previously applied emission factors.

The pollutants for which the emission factors are presented are:

CO	Carbon monoxide
THC	Total hydrocarbons
NOx	Nitrogen oxides
THC + NOx	Total Hydrocarbon + nitrogen oxides
PM (e + w)	Particulate matter (< 10 micrometer) from exhaust and wear
PM (e)	Particulate matter (< 10 micrometer) from exhaust
PN	Particle numbers
CO_2	Carbon dioxide
FC	Fuel consumption

All components have been measured, except for CO_2. CO_2 emission factors have been calculated with the following formula:

$$FC = (EF_{CO2}*f_{CO2}+EF_{CO}*f_{CO}+EF_{HC}*f_{HC})*1/(\text{fuel density}*1000)*100$$

Where:

FC	Fuel consumption (l/100km)
EF	Emission factor (g/km)
f	Ratio compared to the molecular mass of carbon
fuel density	Density of the fuel (0.745 kg/l)

For the emission calculations (see chapter 4), it is necessary to assume that all of the carbon is oxidised. The CO_2 emissions are calculated by multiplying the fuel consumption with a standard emission factor (based on the carbon content of the fuel).

3.1 Euro-2 emission factors for mopeds

Euro-2 emission factors for mopeds are displayed in Table 7 and Table 8, respectively for urban and rural driving behaviour.

Table 7: Euro-2 emission factors for mopeds with urban driving behaviour (2014).

			urban								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	l/100km
4-stroke	25km/h	S	26.70	1.95	0.04	2.00	0.01	0.01	9.09E+12	51.30	4.21
		A	21.34	1.55	0.04	1.59	0.01	0.01	6.40E+12	38.30	3.25
		T	16.25	1.16	0.03	1.19	0.01	0.01	5.54E+12	27.86	2.42
	45km/h	S	18.98	1.20	0.04	1.24	0.01	0.00	5.79E+12	38.56	3.06
		A	17.44	1.36	0.04	1.39	0.02	0.01	5.86E+12	23.53	2.34
		T	16.25	1.16	0.03	1.19	0.01	0.01	5.54E+12	27.86	2.42
2-stroke	25km/h	S	4.83	4.87	0.11	4.99	0.08	0.07	1.38E+13	98.48	5.15
		A	3.67	4.05	0.17	4.22	0.04	0.03	7.75E+12	58.22	3.25
		T	16.37	11.32	0.05	11.37	0.11	0.10	1.68E+13	31.58	3.95
	45km/h	S	3.45	3.48	0.08	3.56	0.06	0.05	9.86E+12	70.34	3.68
		A	3.67	4.05	0.17	4.22	0.04	0.03	7.75E+12	58.22	3.25
		T	16.37	11.32	0.05	11.37	0.11	0.10	2.E+13	31.58	3.95

Table 8: Euro-2 emission factors for mopeds with rural driving behaviour (2014).

			rural								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	l/100km
4-stroke	25km/h	S	21.54	1.10	0.03	1.13	0.01	0.01	1.01E+13	73.19	4.68
		A	23.14	1.31	0.03	1.34	0.01	0.01	8.60E+12	42.03	3.49
		T	14.75	0.87	0.05	0.92	0.01	0.01	4.60E+12	30.30	2.38
	45km/h	S	15.29	0.71	0.03	0.74	0.01	0.00	5.15E+12	52.97	3.31
		A	17.26	1.02	0.03	1.06	0.01	0.01	5.84E+12	27.02	2.43
		T	14.75	0.87	0.05	0.92	0.01	0.01	4.60E+12	30.30	2.38
2-stroke	25km/h	S	4.78	2.51	0.09	2.60	0.06	0.06	2.67E+13	108.35	5.24
		A	3.20	2.04	0.16	2.20	0.02	0.02	1.09E+13	64.30	3.21
		T	17.25	11.67	0.06	11.73	0.14	0.14	2.20E+13	30.72	4.02
	45km/h	S	3.41	1.79	0.06	1.86	0.04	0.04	2.E+13	77.39	3.75
		A	3.20	2.04	0.16	2.20	0.02	0.02	1.E+13	64.30	3.21
		T	17.25	11.67	0.06	11.73	0.14	0.14	2.E+13	30.72	4.02

3.2 Euro-1 emission factors for mopeds

Euro-1 emission factors for mopeds are displayed in Table 9 and Table 10, respectively for urban and rural driving behaviour.

Table 9: Euro-1 emission factors for mopeds with urban driving behaviour (2014).

			urban								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	l/100km
4-stroke	25km/h	S	26.70	2.73	0.04	2.75	0.09	0.08	9.09E+12	51.30	4.34
		A	21.34	2.73	0.04	2.75	0.09	0.08	6.40E+12	38.30	3.42
		T	16.25	2.73	0.03	2.75	0.09	0.08	5.54E+12	29.89	2.73
	45km/h	S	18.98	2.73	0.04	2.75	0.09	0.08	5.79E+12	38.56	3.28
		A	17.44	2.73	0.04	2.75	0.09	0.08	5.86E+12	29.89	2.81
		T	16.25	2.73	0.03	2.75	0.09	0.08	5.54E+12	29.89	2.73
2-stroke	25km/h	S	5.60	4.87	0.11	4.99	0.09	0.08	1.38E+13	98.48	5.22
		A	5.60	4.05	0.17	4.22	0.09	0.08	7.75E+12	58.22	3.40
		T	16.37	11.32	0.05	11.37	0.11	0.10	1.68E+13	31.58	3.96
	45km/h	S	5.60	3.48	0.08	3.56	0.09	0.08	9.86E+12	70.34	3.84
		A	5.60	4.05	0.17	4.22	0.09	0.08	7.75E+12	58.22	3.40
		T	16.37	11.32	0.05	11.37	0.11	0.10	1.68E+13	31.58	3.96

Table 10: Euro-1 emission factors for mopeds with rural driving behaviour (2014.

			rural								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	l/100km
4-stroke	25km/h	S	21.54	2.73	0.03	2.75	0.08	0.08	1.01E+13	73.19	4.92
		A	23.14	2.73	0.03	2.75	0.08	0.08	8.60E+12	42.03	3.70
		T	14.75	2.73	0.05	2.75	0.08	0.08	4.60E+12	30.30	2.64
	45km/h	S	15.29	2.73	0.03	2.75	0.08	0.08	5.15E+12	52.97	3.64
		A	17.26	2.73	0.03	2.75	0.08	0.08	5.84E+12	29.89	2.79
		T	14.75	2.73	0.05	2.75	0.08	0.08	4.60E+12	30.30	2.64
2-stroke	25km/h	S	5.60	2.73	0.09	2.75	0.08	0.08	2.67E+13	108.35	5.35
		A	5.60	2.73	0.16	2.75	0.08	0.08	1.09E+13	64.30	3.48
		T	17.25	11.67	0.06	11.73	0.14	0.14	2.20E+13	30.72	4.03
	45km/h	S	5.60	2.73	0.06	2.75	0.08	0.08	2.E+13	77.39	4.04
		A	5.60	2.73	0.16	2.75	0.08	0.08	1.E+13	64.30	3.48
		T	17.25	11.67	0.06	11.73	0.14	0.14	2.E+13	30.72	4.03

3.3 Euro-0 emission factors for mopeds

Euro-0 emission factors for mopeds are displayed in Table 11 and Table 12, respectively for urban and rural driving behaviour.

Table 11: Euro-0 emission factors for mopeds with urban driving behaviour (2014).

			urban								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	l/100km
4-stroke	25km/h	S	26.70	13.91	0.04	13.93	0.21	0.20	9.09E+12	51.30	5.84
		A	21.34	13.91	0.04	13.93	0.21	0.20	6.40E+12	38.30	4.92
		T	16.25	13.91	0.03	13.93	0.21	0.20	5.54E+12	27.86	4.14
	45km/h	S	18.98	13.91	0.04	13.93	0.21	0.20	5.79E+12	38.56	4.78
		A	17.44	13.91	0.04	13.93	0.21	0.20	5.86E+12	23.53	4.04
		T	16.25	13.91	0.03	13.93	0.21	0.20	5.54E+12	27.86	4.14
2-stroke	25km/h	S	13.80	13.91	0.11	13.93	0.21	0.20	1.38E+13	98.48	6.98
		A	13.80	13.91	0.17	13.93	0.21	0.20	7.75E+12	58.22	5.27
		T	16.37	13.91	0.05	13.93	0.21	0.20	1.68E+13	31.58	4.31
	45km/h	S	13.80	13.91	0.08	13.93	0.21	0.20	9.86E+12	70.34	5.78
		A	13.80	13.91	0.17	13.93	0.21	0.20	7.75E+12	58.22	5.27
		T	16.37	13.91	0.05	13.93	0.21	0.20	1.68E+13	31.58	4.31

Table 12: Euro-0 emission factors for mopeds with rural driving behaviour (2014).

			rural								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	l/100km
4-stroke	25km/h	S	21.54	13.91	0.03	13.93	0.20	0.20	1.01E+13	73.19	6.42
		A	23.14	13.91	0.03	13.93	0.20	0.20	8.60E+12	42.03	5.20
		T	14.75	13.91	0.05	13.93	0.20	0.20	4.60E+12	30.30	4.14
	45km/h	S	15.29	13.91	0.03	13.93	0.20	0.20	5.15E+12	52.97	5.14
		A	17.26	13.91	0.03	13.93	0.20	0.20	5.84E+12	27.02	4.17
		T	14.75	13.91	0.05	13.93	0.20	0.20	4.60E+12	30.30	4.14
2-stroke	25km/h	S	13.80	13.91	0.09	13.93	0.20	0.20	2.67E+13	108.35	7.40
		A	13.80	13.91	0.16	13.93	0.20	0.20	1.09E+13	64.30	5.53
		T	17.25	13.91	0.06	13.93	0.20	0.20	2.20E+13	30.72	4.33
	45km/h	S	13.80	13.91	0.06	13.93	0.20	0.20	1.91E+13	77.39	6.08
		A	13.80	13.91	0.16	13.93	0.20	0.20	1.09E+13	64.30	5.53
		T	17.25	13.91	0.06	13.93	0.20	0.20	2.20E+13	30.72	4.33

3.4 Aggregated emission factors for mopeds

Aggregated emission factors for mopeds are displayed in Table 13 and Table 14, respectively for urban and rural driving behaviour.

Table 13: Aggregated emission factors for mopeds with urban driving behaviour (2014).

			urban								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	g/km
4-stroke	25km/h	E0	24.05	13.91	0.04	13.93	0.21	0.20	7.93E+12	45.06	40.18
		E1	24.05	2.73	0.04	2.75	0.09	0.08	7.93E+12	45.26	29.07
		E2	24.05	1.75	0.04	1.79	0.01	0.01	7.93E+12	45.06	27.89
	45km/h	E0	18.40	13.91	0.04	13.93	0.21	0.20	5.78E+12	34.48	34.02
		E1	18.40	2.73	0.04	2.75	0.09	0.08	5.78E+12	35.96	23.30
		E2	18.40	1.23	0.04	1.27	0.01	0.01	5.78E+12	34.48	21.24
2-stroke	25km/h	E0	14.06	13.91	0.12	13.93	0.21	0.20	1.23E+13	79.71	46.19
		E1	6.68	5.27	0.12	5.39	0.09	0.08	1.23E+13	79.71	33.88
		E2	5.63	5.27	0.12	5.39	0.07	0.06	1.23E+13	79.71	33.22
	45km/h	E0	14.06	13.91	0.10	13.93	0.21	0.20	1.01E+13	64.04	41.22
		E1	6.68	4.38	0.10	4.47	0.09	0.08	1.01E+13	64.04	28.02
		E2	4.79	4.38	0.10	4.47	0.06	0.05	1.01E+13	64.04	26.96

Table 14: Aggregated emission factors for mopeds with rural driving behaviour (2014).

			rural								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	g/km
4-stroke	25km/h	E0	21.34	13.91	0.03	13.93	0.20	0.20	9.10E+12	59.55	43.43
		E1	21.34	2.73	0.03	2.75	0.08	0.08	9.10E+12	59.55	32.25
		E2	21.34	1.14	0.03	1.17	0.01	0.01	9.10E+12	59.55	30.51
	45km/h	E0	15.63	13.91	0.03	13.93	0.20	0.20	5.24E+12	45.51	36.13
		E1	15.63	2.73	0.03	2.75	0.08	0.08	5.24E+12	46.09	25.13
		E2	15.63	0.79	0.03	0.82	0.01	0.00	5.24E+12	45.51	22.65
2-stroke	25km/h	E0	14.14	13.91	0.11	13.93	0.20	0.20	2.15E+13	87.37	48.67
		E1	6.76	3.62	0.11	3.65	0.09	0.09	2.15E+13	87.37	34.70
		E2	5.55	3.28	0.11	3.39	0.06	0.05	2.15E+13	87.37	33.60
	45km/h	E0	14.14	13.91	0.08	13.93	0.20	0.20	1.77E+13	70.11	43.19
		E1	6.76	3.62	0.08	3.65	0.09	0.09	1.77E+13	70.11	29.23
		E2	4.75	2.83	0.08	2.91	0.05	0.05	1.77E+13	70.11	27.30

3.5 Comparison of aggregated emission factors for mopeds 2014 vs. 2011

The absolute difference of aggregated emission factors 2014 in comparison to 2011 are displayed in Table 15 and Table 16 for urban and rural driving behaviour.

Table 15: Comparison of aggregated emission factors for mopeds 2014 vs. 2011, with urban driving behaviour, absolute values (EF2014 – EF2011).

			urban								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	g/km
4-stroke	25km/h	E0	10.2	0.0	0.0	0.0	-	0.0	-	31.8	15.2
		E1	18.4	0.0	0.0	0.0	-	0.0	-	15.4	14.1
		E2	22.7	0.2	-0.2	0.0	-	0.0	-	13.9	15.8
	45km/h	E0	4.6	0.0	0.0	0.0	-	0.0	-	21.2	9.0
		E1	12.8	0.0	0.0	0.0	-	0.0	-	6.1	8.3
		E2	17.1	-0.3	-0.2	-0.6	-	0.0	-	3.4	9.2
2-stroke	25km/h	E0	0.3	0.0	0.1	0.0	-	0.0	-	66.4	21.2
		E1	1.1	2.5	0.1	2.6	-	0.0	-	49.8	18.9
		E2	4.3	3.7	-0.1	3.6	-	0.0	-	48.6	21.1
	45km/h	E0	0.3	0.0	0.1	0.0	-	0.0	-	50.8	16.2
		E1	1.1	1.6	0.1	1.7	-	0.0	-	34.2	13.0
		E2	3.5	2.8	-0.2	2.7	-	0.0	-	32.9	14.9

Table 16: Comparison of aggregated emission factors for mopeds 2014 vs. 2011, with rural driving behaviour, absolute values (EF2014 – EF2011).

			rural								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	g/km
4-stroke	25km/h	E0	7.5	0.0	0.0	0.0	-	0.0	-	46.3	18.4
		E1	15.7	0.0	0.0	0.0	-	0.0	-	29.7	17.2
		E2	20.0	-0.4	-0.2	-0.6	-	0.0	-	28.4	18.4
	45km/h	E0	1.8	0.0	0.0	0.0	-	0.0	-	32.2	11.1
		E1	10.0	0.0	0.0	0.0	-	0.0	-	16.2	10.1
		E2	14.3	-0.8	-0.2	-1.0	-	0.0	-	14.4	10.6
2-stroke	25km/h	E0	0.3	0.0	0.1	0.0	-	0.0	-	74.1	23.7
		E1	1.2	0.9	0.1	0.9	-	0.0	-	57.5	19.7
		E2	4.3	1.7	-0.2	1.6	-	0.0	-	56.2	21.5
	45km/h	E0	0.3	0.0	0.1	0.0	-	0.0	-	56.8	18.2
		E1	1.2	0.9	0.1	0.9	-	0.0	-	40.2	14.2
		E2	3.5	1.3	-0.2	1.1	-	0.0	-	39.0	15.2

The relative difference of aggregated emission factors 2014 in comparison to 2011 are displayed in Table 17 and Table 18 for urban and rural driving behaviour. 0% = no change a positive value is an increase of emissions and a negative value is a decrease of emissions.

Table 17: Comparison of aggregated emission factors for mopeds 2014 vs. 2011, with urban driving behaviour, relative changes.

			urban								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	l/100km
4-stroke	25km/h	E0	74%	0%	104%	0%	-	0%	-	239%	61%
		E1	329%	0%	104%	0%	-	0%	-	51%	94%
		E2	1750%	12%	-84%	-1%	-	-85%	-	45%	131%
	45km/h	E0	33%	0%	89%	0%	-	0%	-	160%	36%
		E1	229%	0%	89%	0%	-	0%	-	20%	55%
		E2	1315%	-21%	-85%	-30%	-	-86%	-	11%	76%
2-stroke	25km/h	E0	2%	0%	517%	0%	-	0%	-	500%	85%
		E1	19%	93%	517%	96%	-	2%	-	167%	126%
		E2	333%	238%	-53%	196%	-	56%	-	156%	175%
	45km/h	E0	2%	0%	376%	0%	-	0%	-	382%	65%
		E1	19%	60%	376%	63%	-	2%	-	114%	87%
		E2	268%	181%	-63%	146%	-	30%	-	106%	123%

Table 18: Comparison of aggregated emission factors for mopeds 2014 vs. 2011, with rural driving behaviour, relative changes.

			rural								
			CO	THC	NOx	THC+ NOx	PM (e+w)	PM (e)	PN	CO_2	FC
			g/km	g/km	g/km	g/km	g/km	g/km	#/km	g/km	l/100km
4-stroke	25km/h	E0	55%	0%	65%	0%	-	0%	-	348%	74%
		E1	281%	0%	65%	0%	-	0%	-	99%	115%
		E2	1541%	-27%	-87%	-36%	-	-86%	-	91%	153%
	45km/h	E0	13%	0%	62%	0%	-	0%	-	243%	45%
		E1	179%	0%	62%	0%	-	0%	-	54%	68%
		E2	1102%	-49%	-88%	-55%	-	-90%	-	46%	88%
2-stroke	25km/h	E0	2%	0%	448%	0%	-	0%	-	558%	95%
		E1	21%	33%	448%	33%	-	7%	-	192%	131%
		E2	327%	110%	-58%	86%	-	34%	-	181%	178%
	45km/h	E0	2%	0%	321%	0%	-	0%	-	428%	73%
		E1	21%	33%	321%	33%	-	7%	-	135%	95%
		E2	266%	81%	-68%	60%	-	15%	-	125%	126%

When comparing emission factors of 2014 with 2011, it can be seen that emission factors of 2014 generally are higher than estimated in 2011. Only, in some specific cases, Euro-2 emission factors of 2014 are lower than estimated in 2011:

- NOx emission factors: This is due to the fact that in 2011 Euro-2 NOx emissions were estimated to be large, 0.26 g/km, in comparison to Euro-1 and Euro-0 factors which were estimated a factor 10 smaller. The new Euro-2 measurements from 2013 show that in the worst case (2-stroke / altered configuration), NOx emissions are 0.17 g/km. In the best case (4-stroke / standard configuration), NOx emissions are 0.04 g/km.
- Specifically 4-stroke engine types turn out to have smaller THC and PM emissions than estimated in 2011. PM emissions are in the range of 0.01 g/km instead of 0.04 g/km.
- Differences for PM10 and PN are not listed, since 'old' emission factors did not include these two parameters.

New emission factors are determined by measurements of Euro-2 mopeds and are therefore expected to be more representative than earlier estimations. However, the measurements have been performed on a very limited number of mopeds. In order to deduce more accurate emission factors, more measurements are required. In comparison to earlier emission factors, the current emission factors include both urban and rural road types. The difference in level of detail (and driving cycle) partly explain the differences between old and new emission factors.

3.6 Emission factors of micro-cars

In The Netherlands in 2012 21.000 micro-cars (4-wheeled vehicles with a maximum allowed speed of 45 km/h) have been on the road. The drivers of these vehicles do not need a driver license. Most of these vehicles are equipped with a two-cylinder diesel engine and must be homologated as a moped. Currently the Euro 2 limit values of mopeds are applicable.

The total number of micro-cars gradually increases and therefore it is needed to obtain an overview of the contribution of these vehicles to the total air pollution. Due to a lack of data the emission factors are estimated by experts.

Currently the majority of the vehicles has a 4 kW 2-cylinder diesel engine with an indirect fuel injection system with EPA TIER 2 technology and this corresponds with Euro 2 technology. Two different manufacturers supply the market.
Since 2010 a third manufacturer applies a direct fuel injection system and they state that this engine has an emission performance of Euro 3 engine.

The engines are not equipped with EGR (Exhaust Gas Recirculation) or after-treatment devices such as catalysts and particulate filters. In Table 19
the main properties of the diesel engines are reported.

Table 19: Properties diesel engines micro-cars.

Trade mark	A	B
Fuel	Diesel	Diesel
Manufacturer	C/D/E	F
Swept volume [cc]	400 - 523	480
No of cylinders	2	2
Fuel injection	IDI	DI
Max. Power[kW]	4	4
Emission standard	Euro 2	Euro 3
Market Share 2013 (estimated)	90%	10%
Sales 2013 (estimated)	40%	60%

The estimated emission factors of micro-cars are based on the emission factors of Euro 2 and 3 passenger cars. In Table 20 Euro 2 emission limit values and emission factors from Euro 2 and 3 passenger cars are reported.

Table 20: Emission factors and fuel consumption of micro-cars, [g/km].

Pollutant	Euro 2*		Euro 3*		Limit value Moped Euro2
	Urban	Rural	Urban	Rural	
CO	0.716	0.241	0.404	0.172	1,00
THC	0.124	0.043	0.026	0.013	1,20
NOx	0.800	0.548	0.796	0.549	
PM	0.111	0.045	0.031	0.026	-
Fuel	41	28	39	27	

*Euro 2 and 3 diesel passenger cars

In Table 21 the estimated average emission factors of micro-cars with diesel engine in 2012 are reported. These averages are calculated with the so-called “two-wheel-model” l [TNO, 2011].

Table 21: Estimated emission average factors micro-cars, [g/km].

Pollutant	Emission factor
NOx	0.67
PM	0.07
CO2	109
CO	0.46
THC	0.08
SO2	0.001
NOx	0.67

4 Emission calculation

4.1 Methodology

The emissions were calculated by multiplying the emission factors (as presented in paragraph 3.4) with the amount of kilometres per vehicle type and per road type. The amount of kilometres per vehicle type and per road type have been calculated with a vehicle population model.

The vehicle population model was based on assumptions on median lifespan and removal rate of the two-wheeled vehicles, combined with two-wheeled vehicle sales data. The outcome of the vehicle population was combined by statistical data on vehicle kilometres from Statistics Netherlands. The model generates an output file containing driven kilometres per vehicle- and road type for the total Dutch two-wheeled vehicle fleet for the total time series 1990 -2013. A detailed description of the model is presented in [TNO, 2011].

There were two modifications to the model since the report from 2011 [TNO, 2011]:

1. The vehicle kilometres from Statistics Netherlands have been updated
2. A distinction between 2-stroke and 4-stroke mopeds was implemented

Vehicle kilometres

The vehicle kilometres from Statistics Netherlands have been updated, including vehicle kilometre statistics per vehicle age class. The new vehicle statistics are available for the years 1990-2013 for motorcycles and 2007-2013 for mopeds. An estimate of vehicle statistics is made for mopeds in the years 1990-2006, based on the emission model. In Table 22 the new statistics are presented per vehicle type and per road type. The euro class is based on the age class data.

Table 22: Vehicle kilometres per vehicle type and Euro class (million kilometres).

	Moped			Micro-car		Motorcycles			
Euro	**0**	**1**	**2**	**2**	**3**	**0**	**1**	**2**	**3**
1990	1708					889			
1991	1311					1036			
1992	1308					1242			
1993	1308					1419			
1994	1341					1526			
1995	1326			4		1609			
1996	1326			8		1785			
1997	1354			19		1860			
1998	1352			29		1928			
1999	1196	152		37		1905	99		
2000	1017	337		45		1852	238		
2001	858	497		52		1801	368		
2002	743	496	105	58		1821	469		

2003	622	455	236	65		1795	466	98	
2004	486	364	325	71		1756	448	213	
2005	426	360	432	76		1688	448	315	
2006	366	340	579	81		1640	457	305	78
2007	341	381	914	85		1593	461	279	181
2008	275	360	1180	92		1561	424	286	289
2009	207	340	1429	97		1471	448	308	366
2010	177	301	1636	99	2	1410	450	315	427
2011	141	253	1772	97	5	1361	448	297	496
2012	116	216	1864	94	8	1316	441	273	552
2013	94	207	1914	91	10	1260	376	311	593

Distinction between 2-stroke and 4-stroke mopeds

There are no official statistics recorded by the RDW, BOVAG or RAI on the number of 2-stroke vs. 4-stroke mopeds. In order to derive a first order estimate on this share op moped engines, information was collected from several news items:

- According to [BOVAG, 2014], since 2007 more 4-stroke mopeds are sold than 2-stroke mopeds. Based on this information, it was assumed that the sales in 2007 consisted of 50% 2-stroke and 50% 4-stroke mopeds. In a discussion with BOVAG in 2011 it was confirmed that the share of 4-stroke mopeds was nearly 0% before 2005. Based on this information and taking into account that 4-stroke engines were available before 2005, it was assumed that sales of 4-stroke engines was 5% before 2000 and gradually increased up to 2007.
- According to [RAI, 2014] large moped manufacturers hardly produce any 2-stroke mopeds anymore. Based on this information, it is assumed that sales in 2011 consisted of 90% 4-stroke and only 10% 2-stroke mopeds.

With the information discussed above, the shares of 2-stroke/4-stroke engines were estimated for the years 2000 to 2012 as shown in Table 23.

Table 23: Shares of sold 2-stroke/4-stroke engines in the years 2000 to 2012.

	<=2000	**2001-2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**>=2011**
2-stroke	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%
4-stroke	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%

4.2 Comparison of emissions

Calculated emissions are compared with the results of previous emission calculation in Table 24. Differences are mainly visible for the most recent years. This reason for this observation is that all of the Euro-2 emission factors have been updated and only some of the Euro-0 and Euro-1 emission factors.

Table 24: Comparison of emissions (tonnes) calculated with the 2014 ('new') and the 2011 ('old') emission factors.

Pollutant	Values	1990	1995	2000	2005	2010	2012
PM (e)	New	342	265	231	135	112	96
	Old	342	265	246	129	113	101
CO_2	New	216.664	162.812	155.366	120.887	195.845	200.860
	Old	135.293	104.984	100.905	68.279	87.955	87.346
CO	New	24.698	19.100	17.152	12.261	25.963	28.313
	Old	23.574	18.293	16.999	8.159	5.259	4.038
CH4	New	1.188	922	784	461	432	390
	Old	1.188	922	825	363	253	212
NOx	New	189	139	143	125	173	168
	Old	34	27	27	148	464	530
THC	New	24.950	19.360	16.456	9.677	9.080	8.188
	Old	24.950	19.360	17.326	7.624	5.310	4.449
SO_2	New	32,8	10,5	7,3	1,5	2,7	2,8
	Old	20,5	6,8	4,7	0,8	1,2	1,2

Particulate matter is only calculated for the exhaust emissions. The wear emissions are calculated separately for the Dutch Emissions Registry and are not part of this report.
CO_2 emissions are calculated based on the fuel consumption and the carbon content, with an emission factor of 3168 g CO2/kg fuel. It is assumed that all of the carbon is oxidised (in contrast to the emission factors presented in chapter 3). The reason is that the IPCC methodology accounts for all of the carbon from CO, CH4 and THC, because it is oxidised to CO_2 in the atmosphere within a period of a few days to 10-11 years (IPCC, 1996).

The trends in emissions are also presented in Figure 1.

The main changes in total emissions compared to the previous emission estimation are:

- Total emissions of PM10 and VOC have only changed moderately. For both pollutants, the emission factors for 4-stroke mopeds decreased and for 2-stroke mopeds increased. This resulted in a similar total emission amount.
- The increase in total CO_2 emissions is caused by an increase in measured fuel consumption. The measured fuel consumption is approximately two times the previously estimated fuel consumption. The CO_2 emission is calculated by multiplying the fuel consumption with the carbon content of the fuel.
- Total emissions of CO only increase in the last years. The 2-stroke Euro-0 emission factors have only changed slightly, resulting in almost no change in the CO emissions before 2000. The difference in 4-stroke emission factors and in Euro-1 and Euro-2 emission factors is much higher (up to an increase of 1750% for the CO emission factor of 4-stroke Euro-2 mopeds), resulting in a large increase of CO emission in the most recent years.
- Total emissions of NOx change for the entire time series. Previously, a sharp increase in emissions was visible, due to the higher Euro-2 emission factors.

The new measurements show that the previous emission factors for Euro-2 were most likely too high.

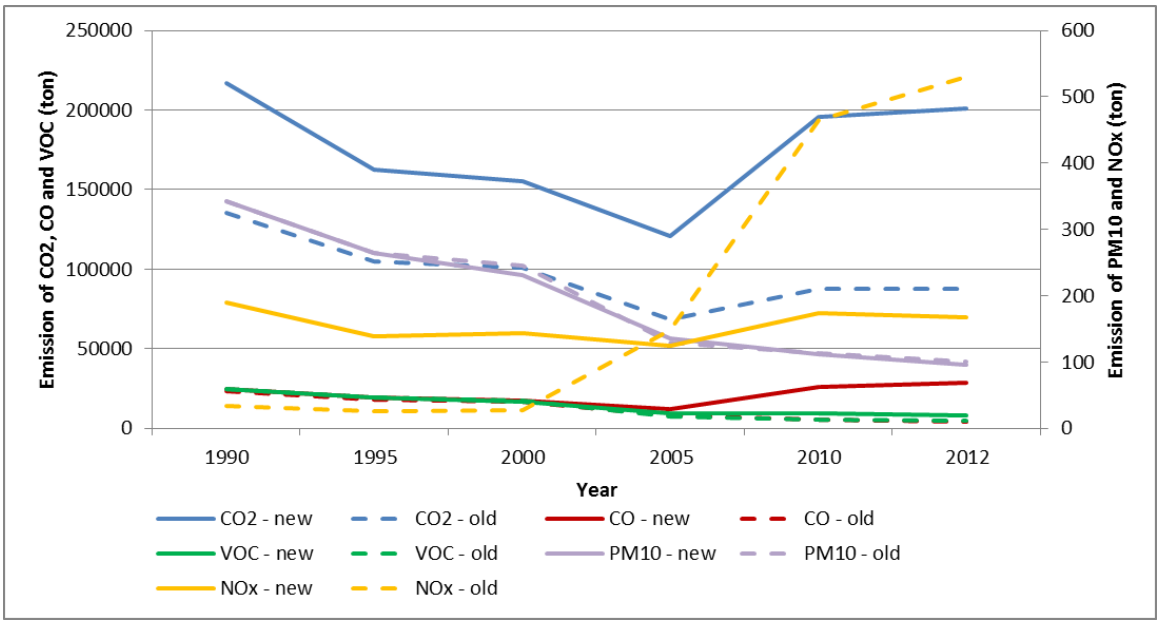

Figure 1: Comparison of emissions (tonnes) of two-wheeled mopeds calculated with the 2014 ('new') and the 2011 ('old') emission factors.

4.3 Emissions of micro-cars (newly added)

Results of the first calculations of emissions of micro-cars on a national scale are presented in this paragraph.
In order to calculate emissions of micro-cars activity data of the number of active vehicles and their mileage are needed. These activity data for a selection of years are presented in Table 25. Most of the activity data were delivered by Statistics Netherlands (CBS). When data were not available the model calculated distances driven with the number of active vehicles times 3900 kilometres per year. However by the influence of the age profile of the vehicles (new vehicles are used more intensively) the actual amount of kilometres per vehicle as modelled changes from year to year.

Table 25: Evolution of the number of active vehicles and total distance driven.

Year	Vehicles active (number)	Data Source	Total distance driven (million km)	Data Source
1995	500	estimated	4.0	modeled
2000	6527	modeled	44.9	modeled
2005	13018	modeled	76.2	modeled
2007	15299	CBS Statline	84.6	CBS
2010	19623	CBS Statline	100.6	CBS
2011	20219	CBS Statline	102.2	CBS
2012	20531	CBS Statline	102.5	CBS

The emission factors as presented in Table 20 and the activity data given in Table 25 were included in the “two-wheel-model” as described in [TNO, 2011].
The results of emission calculation on micro-cars by the “two-wheel-model” are presented in Table 26. After a quick rise of emissions from 1995 to 2010 both the number of micro-cars and their emissions seem to stabilise after 2010.

Table 26: Evolution of emissions of micro-cars, [ton/year].

Pollutant	1995	2000	2005	2010	2011	2012
NOx	3	30	51	68	69	69
PM	0.3	3.5	5.9	7.8	7.8	7.6
CO2	442	4912	8344	11014	11172	11180
CO	2	21	36	48	48	47
THC	0.3	3.7	6.4	8.4	8.3	8.0
SO2	0.50	1.55	0.16	0.07	0.07	0.07

5 Conclusion

The new emission measurements have been used to determine an updated set of emission factors for Euro-2 mopeds. The same measurements have been used to update emissions factors for Euro-0 and Euro-1 mopeds. Based on this update, the total emissions of mopeds in the Netherlands were recalculated for the last years since 1990. Furthermore emission factors of 'micro-cars' with a diesel engine were determined.

Based on the emission factor update, total emissions differ with reference to the emissions calculated in the previous years. The main difference is observed for CO_2 and NOx emissions, NOx emissions are much lower than previously expected, CO_2 emissions are significantly higher. This can be explained with the new test results and the assumptions made in the previous model. Euro-2 NOx emission factors are in the order of 50-80% lower than previous emission factors, Euro-2 CO_2 emission factors are in the order of 200-500% higher. In general, all new emission factors are higher than previously calculated emission factors, with some specific exceptions for NOx and PM for 4-stroke engines.

Emission data of micro-cars are newly introduced. It seems that micro-cars, based on their number and mileage, currently do not represent a significant source of emissions.

6 Discussion and recommendations

The distinction between 2-stroke and 4-stroke mopeds has been based on information from several news items. No exact statistical data was available to make this distinction. This could be improved by combining sales data of mopeds with information on 2-stroke and 4-stroke engine per moped type.

The distinction between standard, tampered and tuned mopeds was based on several studies. The studies might be biased, since the selected locations may not be representative for the average Dutch situation. Tampering and tuning mopeds is an illegal activity and therefore it is difficult to make an exact distinction.

The emission factors are now based on a limited amount of measurements. In order to improve accuracy, it is recommended to perform more measurements, especially for the 25km/h version speed limiter.

In the future the emission factors of micro-cars must be evaluated because certain new cars might be equipped with Euro 3 technology. This affects positively the emission factors of this vehicle category.

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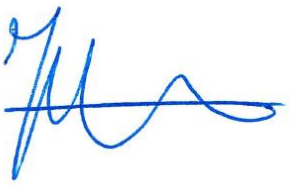

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