Centraal Bureau voor de Statistiek

Memo

Adjustment of heating values and CO_2 emission factors of petrol and diesel

Otto Swertz (team Energy)
Sander Brummelkamp (team Energy)
John Klein (team Environment)
Norbert Ligterink (TNO)

Statistics Netherlands
CBS Den Haag
Henri Faasdreef 312
2492 JP Den Haag
Postbus 24500
2490 HA Den Haag
The Netherlands

+31 70 337 38 00

www.cbs.nl

14 December 2017

Introduction

CO_2 emissions from mobile sources in the Netherlands are calculated based on the formula:
*Emission (kg) = Σtype of fuel sales (kg) * heating value (MJ/kg) * Emission factor (kg/MJ)*
The activity data (i.e. the fuel sales per fuel type) are for the most part derived from the Energy Balance, as reported by Statistics Netherlands (CBS).
The emission factor is derived from the carbon content of the fuels.

Currently CBS applies fixed heating values valid for the entire time series of petrol and diesel fuel for the Dutch market: 44.0 MJ/kg for petrol and 42.7 MJ/kg for diesel fuel. These values were introduced before 1975.
Measurements by TNO in 2016 and RIVM in 2004 showed that these heating values, and also the carbon contents, have changed considerably during the past decades. This made it necessary to adjust the values used in the Dutch CO_2 emission calculations.
The aim of this memo is to determine a consistent time series for 1990-2016 of heating values and CO_2 emission factors for petrol and diesel fuel on the basis of these measurements.

For a description of measurements and their results the reader is referred to the survey reports of TNO (Ligterink, 2016) and RIVM (Olivier, 2004).
The recommendations of the 2016 TNO study relating to petrol were taken up by the Ministry of Infrastructure and Environment. They contracted the Human Environment and Transport Inspectorate (ILT) and TNO to collect random petrol samples across the Netherlands and mix typically 6 petrol samples (ranging from 4 to 7) in equal fractions to a monthly average. These monthly averages were analysed on composition and caloric content. The complete study will run until the end of 2017. Currently, the results of 8 samples from December 2016 till August 2017 are available. These results systematically deviate from the previous study in 2015-2016, in terms of the energy content. The average of 2015-2016 study is outside the current range of the 2017 study. The period from December till August is more or less representative of the annual average, as the autumn fuel transition period is still missing. Therefore, the provisional results, with three-quarter of all samples analysed serves as a good indication of the expected outcome.

It is recommended that the measurements as performed in the 2017 TNO survey will take place on a regular basis in the future, so that CBS can adjust the heating values and CO_2 emission factors when necessary. This applies especially for petrol.

Background

During 1970-2016 major changes occurred in the properties of diesel fuel and petrol, due to:
- the introduction of lead free petrol
- the lowering of the sulphur content of diesel fuel
- the introduction of biofuels (petrol and diesel) which are mixed with the fossil fuels
- the use of new refinery processes

These changes had an effect on the heating values as well as the carbon contents. As these parameters have not been monitored during the entire regarded period a number of assumptions have been made together with the application of the results of the 3 mentioned surveys to develop a time series.

Determination of a time series

In order to create a time series of heating values and CO2 emission factors based on the 1970 values and the 2004, 2015/2016 and 2017 measurements the following data, assumptions and calculations have been applied:

Petrol, heating value

- The lower heating value of the 2015/2016 TNO measurements varies between 40,96 and 42,34 MJ/kg, with an average of 41,65. The carbon weight content ranges between 83.88% and 84.32%, with an average of 84.1.
- The lower heating value of the 2017 TNO measurements varies between 42.07 MJ/kg and 42.56 MJ/kg, with an average of 42.38 MJ/kg. The carbon weight content ranges between 81.6% and 84.9%, with an average of 83.94.
- The measured summer average heating value of 2015 seems too low. Therefore we consider this as an outlier. Taking this into account, the average heating value for market petrol during 2015 till 2017 is estimated 42,3. After correction for the average (bio) ethanol fraction in the samples of 4.6% this results in a heating value for fossil petrol of 43.0 MJ/kg. Ethanol has a heating value of 27.0 MJ/kg (EC Directive 2009/28/EC).
  N.B. Depending on the interpretation of the measurement results the heating value for fossil petrol lies between 42.9 and 43.1. The choice for 43.0 might be somewhat arbitrary, but the consequences for the CO_2 calculations are negligible as the Dutch energy data are collected in kilograms and the emission factors per kg of fuel are not under discussion.
- The CBS heating values for market petrol deviate from the heating values based on the TNO measurements because the share of bio petrol in the national sales differs from the share in the measurement samples.
- The assumed strong decline in the heating value of fossil petrol from 1986 onwards (see table 2) was based on the replacement of lead components by oxygenates. The increase of oxygen leads to lower heating values.
- Because the exact course of the increase of oxygen in petrol is unknown, the average measured lead content has been used as a proxy to estimate the increase of the oxygen content, and therefore the decrease of heating values.
- The measured lead content decreases step by step between 1986 and 1997 due to legislation. From 1997 only lead free petrol is available on the consumer market.
- For lead free petrol without the addition of bio components (1997-2005) the average heating value of 2004 (Olivier, 2004) is applied: 41.2 MJ/kg .
- Bio petrol has been introduced in 2006. From 2010 it consists of ethanol only with a heating value of 27.0 MJ/kg. During 2006-2009 bio petrol also contained bio ETBE and MTBE, leading to a heating value gradually decreasing from 28.0 in 2006 to 27.0 in 2010.
- It is assumed that in recent years there was no need to add oxygenates to the market petrol because the (bio)ethanol content was sufficient to meet the specs on the octane number. For this reason the 2015 (43.0 MJ/kg) value has also been assigned to 1985, the last year without lead replacement by oxygenates.
- As there are no measurements available between 1975 and 1985 the heating value is assumed constant (44 MJ/kg) between 1970 and 1977. In 1978 the value is lowered to 43 MJ/kg based on the decline of the lead content.

Petrol, carbon content

- The carbon content of petrol measured in 2004, which leads to a CO_2 emission factor of 3170 g/kg, has been applied for the entire period 1997-2004. The average CO_2 emission factor for fossil petrol of 3140 g/kg, measured in 2015, has been applied for 2015 and 2016. This factor is based on the results for market fuel and corrected for the average bio fuel content of the samples.
- Between 2004 and 2015 the values have been interpolated on the basis of the biofuel contents in the market fuel.
- It has been assumed that the CO2 emission factor amounted to 3200 g/kg from 1975 to 1985. The 1990 value of 3176 is the result of an interpolation between the 1985 and 1997 values. The course of this interpolation was determined by the decline of the lead content, leading to a higher oxygen content and by that a lower carbon content.

Diesel fuel, heating value

- The current heating value used by CBS is based on the situation in 1970 and applies for fossil diesel fuel: 42.7 MJ/kg.
- The new heating value of fossil diesel is based on the 2004 measurements (43.1 MJ/kg) and the 2015 measurements (43.2 MJ/kg).
- The course of the heating values during 1970-2015 has been determined on the basis of the heating value reducing sulphur content

Diesel fuel, carbon content

- The carbon content of diesel fuel measured in 2004, which leads to a CO_2 emission factor of 3170 g/kg, has been applied for the entire period 1970-2004. The average CO_2 emission factor for market diesel fuel of 3121 g/kg, measured in 2015, has been applied for 2015 and 2016. After correction for the bio fuel content in the samples this leads to 3130 g/kg for fossil diesel fuel.
- Between 2004 and 2015 the values have been interpolated on the basis of the biofuel contents in the market fuel.

General

- Considering the accuracy of the underlying data, only one decimal has been applied for the heating values
- It is the intention of CBS to fix the time series of 1990-2016 as described in this memorandum.
- For 2017 and later, heating values and/or emission factors will be adjusted if new measurements induce to do so.

Lead in petrol and sulphur in diesel fuel

The lead and sulphur contents of motor fuels have been derived from three CBS publications (CBS 1982, 1986, 1992) and a recent Dutch PRTR methodology report (Klein, J., et.al., 2017). Table 1 shows the values from 1970 to 2016.

Results

The results of the adjustments for the heating values and CO_2 emission factors can be found in the accompanying tables 2 and 3. These tables also show the currently used CBS factors and the IPCC defaults.

The consequences of the adjustments of the emission factors for the CO_2 emissions are shown in tables 4 and 5. The figures are based on the state of affairs in September 2017 concerning the Dutch market fuel sales of petrol and diesel fuel used in mobile sources (transport and mobile machinery).
The new figures for carbon content and heating values lead to marginal changes in CO_2 emissions by petrol fuelled mobile sources during 1990-2006 to about minus 3% from 2009 onwards.
The adjustments of the CO_2 emissions by diesel fuelled mobile sources range between marginal during 1990-2006 and minus 1 to 2% from 2007 onwards.

N.B. In 2015 petrol fuelled mobile sources accounted for 7% of the national total of CO_2 emissions and diesel fuelled mobile sources for 13%.

References

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Table 1. Lead in petrol and sulphur in diesel fuel [1)]

	Lead content of petrol	Sulphur content of diesel fuel	Source
	grams/liter	*weight%*	
1970	0.56	0.70	CBS, 1982
1971	0.56	0.70	CBS, 1982
1972	0.57	0.70	CBS, 1982
1973	0.58	0.70	CBS, 1982
1974	0.62	0.50	CBS, 1982
1975	0.54	0.49	CBS, 1982
1976	0.54	0.45	CBS, 1982
1977	0.48	0.43	CBS, 1982
1978	0.37	0.40	CBS, 1986
1979	0.36	0.38	CBS, 1986
1980	0.36	0.33	CBS, 1992
1981	0.36	0.25	CBS, 1992
1982	0.36	0.26	CBS, 1992
1983	0.36	0.24	CBS, 1992
1984	0.37	0.21	CBS, 1992
1985	0.36	0.20	CBS, 1992
1986	0.24	0.23	CBS, 1992
1987	0.10	0.24	CBS, 1992
1988	0.10	0.23	CBS, 1992
1989	0.09	0.17	CBS, 1992
1990	0.071	0.18	Klein, J., et. al., 2017
1991	0.057	0.18	Klein, J., et. al., 2017
1992	0.042	0.18	Klein, J., et. al., 2017
1993	0.036	0.18	Klein, J., et. al., 2017
1994	0.027	0.18	Klein, J., et. al., 2017
1995	0.021	0.17	Klein, J., et. al., 2017
1996	0.011	0.14	Klein, J., et. al., 2017
1997	0.0004	0.088	Klein, J., et. al., 2017
1998	0.00001	0.086	Klein, J., et. al., 2017
1999	0.00001	0.084	Klein, J., et. al., 2017
2000	0.00001	0.067	Klein, J., et. al., 2017
2001	0.00001	0.050	Klein, J., et. al., 2017
2002	0.00001	0.046	Klein, J., et. al., 2017
2003	0.00001	0.044	Klein, J., et. al., 2017
2004	0.00001	0.042	Klein, J., et. al., 2017
2005	0.00001	0.041	Klein, J., et. al., 2017
2006	0.00001	0.039	Klein, J., et. al., 2017
2007	0.00001	0.033	Klein, J., et. al., 2017
2008	0.00001	0.021	Klein, J., et. al., 2017
2009	0.00001	0.010	Klein, J., et. al., 2017
2010	0.00001	0.006	Klein, J., et. al., 2017
2011-2016	0.00001	0.001	Klein, J., et. al., 2017

[1)] Averages for Dutch market fuels

Table 2. Petrol and diesel fuel, heating values [1)]

	Heating value of petrol			Heating value of diesel fuel			
	market	fossil	bio	maritime	market	fossil	bio
	MJ/kg of fuel			*MJ/kg of fuel*			
IPCC default [2)]		44.3				42.7	
CBS Current (1990-2016)	44.0	44.0		42.7	42.7	42.7	
New							
1975	44.0	44.0				42.7	
1980	43.0	43.0				42.9	
1985	43.0	43,0				43.0	
1986	42.4	42.4				43.0	
1987	41.7	41.7				43.0	
1988	41.7	41.7				43.0	
1989	41.6	41.6				43.0	
1990	41.6	41.6		43.0	43.0	43.0	
1991	41.5	41.5		43.0	43.0	43.0	
1992	41.4	41.4		43.0	43.0	43.0	
1993	41.4	41.4		43.0	43.0	43.0	
1994	41.3	41.3		43.0	43.0	43.0	
1995	41.3	41.3		43.0	43.0	43.0	
1996	41.3	41.3		43.1	43.1	43.1	
1997	41.2	41.2		43.1	43.1	43.1	
1998	41.2	41.2		43.1	43.1	43.1	
1999	41.2	41.2		43.1	43.1	43.1	
2000	41.2	41.2		43.1	43.1	43.1	
2001	41.2	41.2		43.1	43.1	43.1	
2002	41.2	41.2		43.1	43.1	43.1	
2003	41.2	41.2		43.1	43.1	43.1	37.0
2004	41.2	41.2		43.1	43.1	43.1	37.0
2005	41.2	41.2		43.1	43.1	43.1	37.0
2006	41.3	41.4	28.0	43.1	43.1	43.1	37.0
2007	41.8	42.2	28.0	43.1	42.9	43.1	37.0
2008	41.8	42.4	27.7	43.2	43.0	43.2	37.0
2009	42.0	42.8	27.2	43.2	42.9	43.2	37.0
2010	42.0	42.8	27.0	43.2	43.1	43.2	37.0
2011	42.0	42.9	27.0	43.2	43.0	43.2	37.0
2012	41.9	42.7	27.0	43.2	43.0	43.2	37.0
2013	42.0	42.8	27.0	43.2	43.0	43.2	37.0
2014	42.1	42.9	27.0	43.2	42.9	43.2	37.0
2015	42.1	43.0	27.0	43.2	43.0	43.2	37.0
2016	42.2	43.0	27.0	43.2	43.0	43.2	37.0

[1)] Averages for Dutch market fuels.
[2)] According to 2006 IPCC guidelines for National Greenhouse Gas Inventories.

Table 3. Petrol and diesel fuel, new CO_2 emission factors

	Petrol		Diesel		Petrol		Diesel	
	fossil	bio	fossil	bio	fossil	bio	fossil	bio
	grams/kg of fuel				*grams/MJ*			
IPCC default [1)]	3070		3186		69.3		74.1	
The Netherlands								
Current [2)] (1990-2016)	3168		3110		72.0		74.3	
New								
1985	3200		3170		74.4		73.7	
1990	3176		3170		76.3		73.7	
1991	3175		3170		76.5		73.7	
1992	3174		3170		76.7		73.7	
1993	3173		3170		76.6		73.7	
1994	3172		3170		76.8		73.7	
1995	3172		3170		76.8		73.7	
1996	3171		3170		76.8		73.7	
1997	3170		3170		76.9		73.5	
1998	3170		3170		76.9		73.5	
1999	3170		3170		76.9		73.5	
2000	3170		3170		76.9		73.5	
2001	3170		3170		76.9		73.5	
2002	3170		3170		76.9		73.5	
2003	3170		3170	2842	76.9		73.5	76.8
2004	3170		3170	2842	76.9		73.5	76.8
2005	3170		3170	2842	76.9		73.5	76.8
2006	3166	1910	3167	2842	76.5	68.2	73.5	76.8
2007	3153	1910	3135	2842	74.7	68.3	72.7	76.8
2008	3149	1910	3133	2842	74.3	68.9	72.5	76.8
2009	3143	1910	3130	2842	73.4	70.3	72.5	76.8
2010	3143	1910	3155	2842	73.4	70.7	73.0	76.8
2011	3141	1910	3140	2842	73.2	70.7	72.7	76.8
2012	3141	1910	3132	2842	73.6	70.7	72.5	76.8
2013	3141	1910	3130	2842	73.4	70.7	72.5	76.8
2014	3141	1910	3130	2842	73.2	70.7	72.5	76.8
2015	3140	1910	3130	2842	73.0	70.7	72.5	76.8
2016	3140	1910	3130	2842	73.0	70.7	72.5	76.8

[1)] According to 2006 IPCC guidelines for National Greenhouse Gas Inventories

[2)] Source: Zijlema, P.J., 2015.

Table 4. Petrol sales and CO_2 emissions, 1990-2016

	Dutch market sales [1]		CO_2 emissions IPCC based on		
	fossil petrol	biopetrol	old emission factors [1]	new emission factors	difference
	mln kgs		*million kgs*		*%*
1990	3436		10879	10911	0.1
1991	3455		10937	10969	0.1
1992	3591		11369	11397	0.1
1993	3793		12010	12034	0.1
1994	3890		12319	12339	0.1
1995	4003		12679	12695	0.1
1996	4177		13226	13244	0.1
1997	4130		13082	13093	0.1
1998	4153		13154	13164	0.1
1999	4153		13154	13166	0.1
2000	4029		12758	12771	0.1
2001	4122		13054	13066	0.1
2002	4168		13205	13212	0.1
2003	4185		13255	13268	0.1
2004	4142		13118	13129	0.1
2005	4104		13003	13009	0.0
2006	4142	28	13155	13116	-0.3
2007	4052	132	12990	12777	-1.6
2008	4010	163	12893	12630	-2.0
2009	3958	213	12796	12441	-2.8
2010	3960	208	12801	12448	-2.7
2011	4004	231	12965	12577	-3.0
2012	3846	193	12419	12081	-2.6
2013	3740	194	12086	11748	-2.7
2014	3630	199	11745	11401	-2.9
2015	3674	220	11912	11536	-3.2
2016	3802	187	12272	11938	-2.7

1) State of affairs September 2017.

Table 5. Diesel fuel sales and CO_2 emissions, mobile sources 1990-2016

	Dutch market sales [1]				CO_2 emissions IPCC based on		
	Fossil diesel fuel			biodiesel	old emission factors [1]	new emission factors	difference
	road traffic	maritime	other				
	mln kgs				*million kgs*		*%*
1990	4105	523	907		17564	17548	-0.1
1991	4244	526	904		18001	17984	-0.1
1992	4611	500	897		19062	19045	-0.1
1993	4712	499	954		19560	19543	-0.1
1994	4478	517	935		18813	18796	-0.1
1995	4487	557	952		19026	19009	-0.1
1996	4712	555	1009		19912	19894	-0.1
1997	4801	550	953		20001	19984	-0.1
1998	5040	564	953		20801	20784	-0.1
1999	5281	584	967		21676	21659	-0.1
2000	5473	577	984		22317	22298	-0.1
2001	5504	587	1011		22531	22512	-0.1
2002	5707	544	954		22860	22841	-0.1
2003	5927	501	945		23394	23374	-0.1
2004	6141	490	930		23987	23967	-0.1
2005	6248	504	940		24406	24386	-0.1
2006	6520	503	939	28	25260	25211	-0.2
2007	6663	494	748	132	25080	24717	-1.4
2008	6733	476	811	163	25444	25056	-1.5
2009	6365	465	744	213	24032	23586	-1.9
2010	6375	516	882	208	24663	24502	-0.7
2011	6468	508	821	231	24740	24435	-1.2
2012	6206	452	720	193	23409	23040	-1.6
2013	6014	487	804	194	23177	22788	-1.7
2014	5539	425	778	199	21390	20938	-2.1
2015	5550	502	833	220	21846	21490	-1.6
2016	5485	474	845	187	21586	21234	-1.6

[1] State of affairs September 2017.