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TNO report

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Dutch market fuel composition for GHG emissions

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Summary

For international reporting of CO_2 emissions the Netherlands is using national figures on the CO_2 emissions of road transport, such as the CO_2 per kilogram fuel, and the CO_2 per MJ energy content. These numbers were last updated in 2004, prior to the large scale admixture of biofuels in market fuels for road transport. This study provides data to update the fuel-based CO_2 emission factors to the current situation.

Objective of this study is, primarily, to obtain the CO_2 emission factors for petrol and diesel fuels in the relevant metrics. In the course of the project the determination of the fossil and the bio-admixture contributions were established as relevant and separately investigated.

Fuels were collected at the consumer fuel stations across the Netherlands in 2015. Both summer and winter fuels, of petrol and diesel, were included and analysed for relevant physical-chemical properties. Heating value, density and carbon content were determined, among other aspects.

For diesel fuel the findings are in line with previous and international results. About 3% FAME is added to diesel, slightly lowering the heating value. The fossil component remains similar to the fossil diesel without FAME. For petrol fuel, in contrary, the fossil component in fuel with bio-admixture is different from traditional fossil petrol, without bio-admixture. In particular the heating value is lower, yielding a lower CO_2 reduction of the admixture of ethanol than based on the separate properties of traditional fossil petrol and ethanol. The variation of the fossil component differs also substantially between summer and winter petrol.

Table 1 Summary of the findings based on a 50%/50% summer and winter fuel combination, compared with the Statistics Netherlands (CBS) values over 2013.

market fuels with bio-admixture		heating value [MJ/kg]	carbon content [g/MJ]
petrol	Statistics Netherlands 2013	43.20	69.8
	this study	41.65	74.0
diesel	Statistics Netherlands 2013	42.50	72.2
	this study	43.01	72.5

The conclusions of this study regarding the effects of bio-admixture to automotive fuels on CO_2 emissions can be summarised as follows:

- For diesel fuel the findings are in line with previous and international results. About 3% FAME is added to diesel, lowering the heating value by about 0.1%. The numbers are similar to the values currently used for international CO_2 reporting are correct.

- For petrol fuel in contrary, the CO_2 reduction of the bio-admixture can be up to 50% lower due to a reduced energy content of the fuel, on top of the expected effect from admixture of ethanol in petrol. This was the case for most of the summer fuel samples. The winter fuels are more in line with previous findings.

On the CO_2 monitoring based of fuel sold the current findings have limited effect as the carbon content is in line with previous results. Based on energy content the differences and the variations are substantial.

- In order to monitor the effectiveness of bio-admixture to fuels, it is recommended to continue the monitoring of petrol fuel properties on a regular basis. This can be used to update emission factors in the future and can provide input to future fuel quality requirements. Moreover, water content is not controlled by current fuel specification, and may affect the petrol in a more significant manner than found here. It is recommended to monitor diesel fuel properties occasionally.

Contents

1 Introduction

The Netherlands reports the CO_2 emission of road transport internationally as part of a number of international agreements. Foremost, CO_2 is an important Greenhouse Gas (GHG) contributing to the global warming. The total CO_2 emission is reported to the UNFCCC. Moreover, the monitoring of mitigation measures to reduce the GHG emissions rely on the accurate monitoring of relevant properties and quantities. The admixture of biofuels, which targets are set in the Renewable Energy Directive (RED), ensures the energy usage from renewable sources. See Table 2 for the last report for the RED by the NEa. For proper monitoring appropriate basic numbers are needed, such as the CO_2 emissions related to fuel sold [CO_2 g/g] and CO_2 emission related to the energy consumption [CO_2 g/MJ]. The Fuel Quality Directive (FQD) regulates that the appropriate values are used in the monitoring. The Netherlands uses specific national values for international reporting. In 2004 these numbers were last updated[1], and with the increasing admixture of biofuels an update was appropriate. This report is an extended measurement report of fuel samples taken at the consumer fuel stations across the country.

Table 2 The reported values for the FQD by the NEa ("*Rapportage hernieuwbare energie 2014"*, NEa) with the emission factors used for this reporting.

	FQD Berekening 2014							
		Volume [l]	**Energie/volume [MJ/l]**	**Energie [TJ]**	**Standaard emissiefactor [g/MJ]**	**Emissie [ton CO2]**	**Berekende emissiefactor [g/MJ]**	**Reductie t.o.v. EU referentie [%]**
Sectie I	**Uitslag fossiel inclusief biocomponent**							
	Benzine uitslag			168.290,7578				
	Blanke diesel uitslag			275.418,2288				
	Blanke diesel naar bunkers	67.049.734	36,0	2.413,7904				
	Rode diesel rivierbunkers			52.178,4113				
	Totaal diesel uitslag			330.010,4305				
Sectie II	**Uitslag fossiel zonder biocomponent**							
	LPG uitslag			9.960,0455	73,6	733.059,3476	73,6	16,6%
	LNG uitslag			258,8537	76,7	19.854,0765	76,7	13,1%
	CNG uitslag (Nm3)			0,0000	76,7	0,0000	-	
Sectie III	**Biocomponent = bio bestemd voor naleving**							
	Benzine vervanger			6.166,0192		246.814,3049	40,0	54,7%
	Diesel vervanger			9.811,7969		184.209,5588	18,8	78,7%
	Biogas			237,5128		5.047,7470	21,3	75,9%
	Elektriciteit			10,4748		833,7958	79,6	9,9%
Sectie IV	**Netto fossiele component**							
	Netto benzine			162.124,7386	87,5	14.185.914,6315	87,5	0,9%
	Netto diesel			320.198,6336	89,1	28.529.698,2572	89,1	-0,9%
Sectie V	**Resultaten**							
	Totaal			508.768,0751		43.905.431,7193		
	Gemiddelde NL broeikasgasemissie [g/MJ]				86,3	Berekend		
	EU referentiewaarde [g/MJ]				88,3	Referentiewaarde		
	Emissiereductie t.o.v. referentiewaarde							**2,3%**

The admixture of biofuels reduces the energy content of market fuels, because ethanol, FAME, MTBE, and ETBE do not have the same energy density as fossil fuels, petrol and diesel, from the refinery. In the energy statistics, of the Statistics Netherlands (CBS), this effect is compensated for solely by the properties of the bio-admixture itself. However, due to the bio-admixture, the oil company may decide to change the properties of base fuel.

[1] *Netherlands' CO_2 emission factors for petrol, diesel, and LPG*, J.G.J. Olivier, MNP memorandum, December 2004.

This can also lead to differences in CO_2 emission and energy content. The actual energy density of the fossil component of the fuel is unknown. In 2004 it was already reported that the energy density exhibited the largest variation of all the relevant fuel properties, such as density and carbon fraction, affecting the CO_2 emissions. With the admixture of biofuels it was unclear how this situation changed.

Underlying these discussion is not only the heating value but also the carbon content. The carbon content of automotive fuels is determining the greenhouse gas emissions of road transport. Hence, a good understanding of this carbon content and its variability in market fuels is also essential in determination of greenhouse gas emissions and the effectiveness of mitigation measures. In particular, biofuel admixture is meant to reduce the total greenhouse but will also affect the fuel composition, and therefore the carbon content. Moreover, it affects the fuel quality, in particular heating value, and therefore the variation in the amount of fuel needed for the same transport demand. The heating value mainly determines the amount of fuel needed for the same transport demand (the influence of the variation in fuel properties is considered to have a negligible effect on engine efficiency).

1.1 Objective

To investigate the influence of bio-admixture to petrol and diesel fuel on the fuel properties which determine the CO_2 emissions. These are primarily the heating value (energy content) and the carbon content of the fuel.
Influence fuel properties on CO_2 emissions reporting The different metrics of reporting carbon content are aimed at different ways of reporting greenhouse gas emissions:

- [g/g] carbon content is used to report the CO_2 emissions based on the fuel sold in weight units, typically at the source and in trade.
- [g/liter] carbon content is used to report CO_2 emissions based on refuelling information from consumer's fuel stations.
- [g/MJ] carbon content is used to compare different types of fuels and handle bio-admixture in a uniform manner.

In 2004 the last Dutch study was performed to determine the carbon content in the metrics above, and these results have been used up to date in the official reporting of greenhouse gas emissions. Separately, JRC/CONCAWE has provided in the past the carbon content in all of these three metrics. The 2006 IPCC guidelines are roughly based in this information.

Table 3 JRC/Concawe typical values for market fuels.

Fuel		Density	LHV	Carbon	CO2 emissions		
		kg/m3	MJ/kg	%m	kg/kg	g/MJ	g/l
Gasoline	2002	750	42.9	87.0	3.19	74.35	2393
	2010	745	43.2	86.5	3.17	73.38	2362
Ethanol		794	26.8	52.2	1.91	71.38	1517
Diesel	2002	835	43.0	86.2	3.16	73.54	2639
	2010	832	43.1	86.1	3.16	73.25	2629

Already in 2004 it was observed that the largest variability in the fuel was the heating value, and not the density or weight fraction of carbon.

Hence, in the current study special attention was given to ensure sufficient data was collected to investigate issues concerning the caloric value. With bio-admixture, the heating value is expected to decrease according to the weight fractions of the different components in the fuel. For example, based on standard JRC/Concawe figure as shown in Table 3 one could conclude that the lower heating value of e.g. 4.5% mass fraction ethanol admixture will lead to a reduction of the heating value from 43.20 MJ/kg to 42.46 MJ/kg. This is a 1.7% reduction of energy in a kilogram of fuel. The fossil component has a higher energy density, and replacing it with ethanol will reduce the energy density. Consequently, a 4.5% admixture of ethanol does not yield a similar percentage reduction in CO_2 emission for the same energy. The admixture of 4.5% ethanol, without associated CO_2 emissions, corresponds to 2.8% reduction in CO_2 emissions based on the energy from renewable sources, in this case. These effects are taken into account in the Statistics Netherlands (CBS) energy statistics, in Table 4, where the fossil component of the fuel and the bio-admixture are reported separately. The fossil component has a caloric value of 44 MJ/kg, combined with 5% ethanol, a net market fuel of 43.2 MJ/kg is reported as expected based on the exercise above.

Table 4 The 2015 Statistics Netherlands (CBS) data used to determine energy usage and CO_2 emission for emission inventories.

basis data IPCC as used by CBS

		year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
density															
	benzine	*kg/liter*	0.747	0.750	0.750	0.749	0.750	0.750	0.748	0.748	0.748	0.748	0.748	0.747	
	biobenzine	"					0.750	0.750	0.748	0.750	0.748	0.748	0.750	0.750	
	dieselolie	"	0.836	0.837	0.837	0.836	0.836	0.837	0.837	0.836	0.837	0.838	0.838	0.837	
	biodiesel	"		0.885	0.885	0.885	0.885	0.885	0.879	0.884	0.884	0.882	0.884	0.884	
heating value															
	benzine-totaal	*MJ/kg*	44.0	44.0	44.0	44.0	**43.9**	**43.5**	**43.4**	**43.1**	**43.2**	**43.1**	**43.2**	**43.2**	bioadmixture
	benzine-fossiel	"	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	
	biobenzine	"					27.9	27.9	27.8	27.1	27.0	27.0	27.0	27.0	
	dieselolie-totaal	"	42.7	**42.7**	**42.7**	**42.7**	**42.7**	**42.5**	**42.5**	**42.5**	**42.6**	**42.5**	**42.5**	**42.5**	bioadmixture
	dieselolie-fossiel	"	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	
	biodiesel	"		36.9	36.9	36.9	36.9	36.9	37.1	37.0	37.0	37.0	37.0	37.0	

The reduction of the lower heating value of different bio-admixtures for the market fuels is known and understood. However, most bio-admixtures are oxygenated fuels. The burn characteristics of oxygenated fuels are typically good, and lead to a fast and stable flame. Hence, it is possible to achieve the proper fuel quality with the use of oxygenated fuels, from a base fuel outside the fuel specification. Therefore, it may be possible to use a different base fossil component; not satisfying the fuel specification, and bring it into specification by the use of bio-admixture. The quality of the base fuel and how it will affect the market fuel is part of this study. Therefore, there is some redundancy build into the chemical analyses. In the case of similar bio-admixture, it can be tested whether the main fuel characteristics are the same. Variations in the fuel composition with the same bio-admixtures means that the relevant fuel properties are not fully controlled by assigning only end criteria of market fuels. The original fuel specification was based on refinery products, with further adaptions to allow for bio-admixture. For example, fossil fuel can contain only a very minor amount of water, but with the admixture of ethanol, the amount of water petrol can contain increased manifold.[2] There is, however, no specification for water content beyond the "clear and bright", i.e., no separated water or bubbles.

[2] Evaluation of gasoline–ethanol–water ternary mixtures used as a fuel for an Otto engine, A. Kyriakides, et al., Fuel 108 (2013) p. 208-215.

This water content in fuels is therefore another aspect of this new fuel landscape, which is the result of bio-admixture. Oxygenated fuel may contain a substantial amount of water without separation occurring. Pure hydrocarbons allow only very little water before the fuel turns cloudy. Well known is the water in ethanol, which is difficult to remove completely. In the EN 228 fuel specification there is no specification for water content, except for the “bright and clear”, and it was impossible to have much water blended in hydrocarbons. The ethanol added to the fuel may contain 0.3% water, according to EN 15376, tested according EN 15489. This would mean that with the typical admixture of 4.5% ethanol, 0.0135% water can be in petrol as result of the ethanol admixture. In this study the water content is almost always higher. With the other oxygenated components: MTBE, ETBE, and methanol some additional water can be in the fuel, but the water concentration almost always exceeds the maximal allowable fraction that can arise from the oxygenated components. In hydrocarbon fuels, large amount of water will separate from the hydrophobic fuel and a small amount of water will show as cloudiness. This effect will depend strongly on the temperature.

2 Test and analysis program

In 2015 fuel samples were collected from fuel stations for consumers. Due to the high cost of chemical analyses special care is taken to have a representative sampling, rather than a random sampling of market fuels.

2.1 Sample collection

It is expected that different fuel companies use the same depot fuels. Hence, it is essential to ensure a proper variation in the collected fuels to collect across the Netherlands in different distribution and safety regions because fuel transport is not likely to be interregional. In this manner different depot fuels are sampled.

Moreover, the fuel is collected at different fuel companies to ensure the fullest variation. The collection was carried out in three periods of about ten days each:
- The first winter fuel samples (24 - 31 March 2015)
- The summer fuel samples (14 - 26 August 2015)
- The second winter fuel samples (23 December 2015)

In total 25 petrol and 19 diesel fuel samples were collected by TNO employees who participated according to their travelling to different regions of the Netherlands. The sample bottles were special wide-neck fuel-sample bottles of glass with a double cap (soft plastic inner cap to reduce spillage, and a hard outer cap to avoid diffusion of volatile fractions). The bottles were handed out closed, and opened solely at the moment of collecting at the refueling stations.

The refuelling stations were of nine different fuel companies, including brand names and budget stations. No brand-less stations ("witte pompen") were selected. Fuel companies who advertise with special fuels, outside the diesel and petrol (Euro-95 and Euro-98[3], suitable for Euro-4 vehicles) specification were excluded from the sample collection. No other premium fuels were sampled, only regular fuels with the two octane numbers. Since only a few samples were collected per brand, the brand names are not reported. The deviating findings may have been accidental for the particular brands and it is not known if findings are systematic.

[3] In this report "premium" petrol is the octane 98 petrol suitable for older vehicles. In the Netherlands "premium" is also understood as brand fuels with special additives (Shell Fuel Save, BP Excellium, Texaco XL, Esso Synergy, etc.). These fuels were not selected. "Premium" refers in this report to regular "Super" with octane 98.

Figure 1 The sample bottles of the summer fuel collection: all clear and bright, but with a large variation in colour.

The number of samples is limited, due to the high cost of chemical analyses. The large variations for some fuel properties are large, but are expected to give the bandwidth of common Dutch market fuels.

2.2 Sample analysis

The chemical analyses were carried out by a specialized and certified chemical laboratory. It contained the following type of fuels:

- regular petrol (Euro-95):
  determination of density, C-H-N fractions, LHV, aromatics content, H_2O

- “premium” petrol (Euro-98): (~3% market share)
  determination of density, C-H-N fractions, LHV, aromatics content, H_2O

- Diesel:
  determination of density, C-H-N fraction, FAME content, LHV

Analysis methods used were:

For all fuels:
- C,N,H content fractions via ASTM D5291
- Density via EN ISO 12185
- Heating value (LHV) via ASTM D240 (using ASTM D5291)

Specific analysis for diesel:
- FAME content via EN 14078

Specific analyses for petrol and premium (second and third batch):
- Chemical composition via EN ISO 22854
- Water content via EN ISO 12937

In the first 8 chemical analyses, the chemical analysis of the detailed composition of petrol was not requested. These results, showing large variation in caloric value, raised questions to the actual composition that the subsequent analyses the composition was determined as well. The carbon content and heating value averages are therefore based on a larger sample than the average ethanol, ETBE, and MTBE content.

In principle fuels satisfy the EN 590 (Diesel) and EN 228 (Petrol) fuel specifications. In the Netherlands there is only a legal obligation to satisfy the reduced specification of the Fuel Quality Directive. The Inspection authority of Transport and Environment (ILenT) sees to that. The current analyses only have a minor overlap with these specifications (density and aromatics content) and implicitly via EN ISO 15376, for the requirements of the ethanol prior to admixture, some upper limit to the consequent water content of petrol is determined. There is no direct requirement for maximal water in petrol, apart from bright and clear. With 5% ethanol, in principle, up to 1% water can be added as well. With higher fractions of ethanol the water content can increase even more, without a cloudiness appearance.

3 Results

Especially the heating value of petrol show unexplained variations across the samples. Given that the same test method yields very stable results for the diesel, and the re-testing of samples show minimal variations, it is expected the results can be taken at face value. The issues concerning the fuels are not limited to particular brands or brand segments.

Table 5 The results from the test program, with the variations therein defined as the standard deviation divided by the average. This includes the bio-admixtures, the fossil components are determined from subtracting the average admixtures.

	petrol				diesel			
	winter	variation	summer	variation	winter	variation	summer	variation
density [g/ml]	730.4	0.7%	745.5	0.6%	835.4	0.4%	833.6	0.5%
heating value [MJ/kg]	42.34	1.2%	40.96	5.5%	42.98	0.8%	43.05	0.4%
carbon content [%]	83.88	1.1%	84.23	0.7%	85.19	1.1%	84.98	0.6%
total CO2 emissions								
CO2 [g/g]	3.076		3.088		3.124		3.116	
CO2 [g/MJ]	72.64		75.39		72.68		72.38	
CO2 [g/l]	2246		2302		2609		2597	
fossil only	excluding 4.69% ethanol				excluding 3.18% FAME			
CO2 [g/g]	3.133		3.146		3.133		3.125	
CO2 [g/MJ]	72.69		75.52		72.59		72.27	
heating value [MJ/kg]	43.10		41.66		43.17		43.24	

The caloric value results of the summer petrol are heavily influenced by one outlier at 34.87 MJ/kg. This sample was tested again a few weeks later (some deterioration may have occurred) with a very similar result of 34.76 MJ/kg. Excluding this exceptional sample the average of summer petrol was 41.71 MJ/kg (+/- 1.7%). However, without an apparent fault in either the measurement, other properties, and the collection of the sample, the sample should be included in the average. These values are much lower than the value of 43.2 MJ/kg (44 MJ/kg for the fossil component, therefore based on 5% ethanol admixture) currently used by the Statistics Netherlands (CBS). See Table 3.

The physical properties, such as carbon content, heating value, and density are based on the available samples. The detailed composition is only available for a limited set. In this set there is a clear distinction between Euro-95, the largest fuel group, and Euro-98 which plays a minor role in the sales. The former has mainly ethanol admixture at 4.69% and some MTBE at 1.84%, while the latter has substantial amount of MTBE but no ethanol. From bio-MTBE only 36% is bio-component, and the heating-value attribution should be based on methanol. However, MTBE is also added as anti-knocking agent and it is, mainly, not from renewable sources. Even the bio-MTBE altogether is not fully renewable, as it is derived from bio-methanol and hydrocarbons. The latter is typically fossil and has the higher heating value of the two components. Assigning the CO_2/MJ according to weight to the bio-admixture overestimates the CO_2 reduction of MTBE. In this study only the ethanol is assumed a bio-admixture, the sole non-fossil component in petrol.

The winter samples were collected in two consecutive winters. The results of the first winter show a much wider variation in heating value than the results of the second winter. The second set of samples, from December 2015, were more homogeneous.

In the results the carbon content is somewhat lower than would be expected on the basis of the common used data from the literature. This lowers the CO_2 emissions based in fuel sold, in weight units, somewhat. On the other hand the density of petrol is lower than both the Statistics Netherlands (CBS) and JRC use, which means that per litre sold the energy is even lower compared to the commonly used figures, based on the density and energy per kilogram.

3.1 Diesel fuel

The diesel results are very stable for heating value, density, and carbon content, although the variation of FAME content is large for both the summer and winter fuels. Higher FAME content yields on average a marginally lower heating value and density. The FAME has average admixtures fractions in the winter fuel of 3.1% and the summer fuel of 3.2%. The annual average from these samples is 3.18%, with a wide variation. The consequences are limited, since FAME has a relatively high heating value at 37.2 MJ/kg[4]. On average the reduction of heating value per kilogram is therefore 0.4%.

In the future it is expected that HVO will be added to diesel, since there is little restriction on the amount of HVO that can be added to the diesel. HVO is a plain paraffinic fuel (non-oxygenated). Using HVO it is therefore easier to achieve the targets of the RED. Currently, negligible other oxygenated components, apart from FAME were found. However, for future fuel monitoring this must be taken into consideration.

3.2 Petrol fuel

Water was determined in most of the samples. The amount of water is well below 1% with an average of 0.032% with a variation around it, but large compared to the expected value based on the admixture of dry ethanol, which is in the order of 0.015%. None of the samples has this low amount of water. In some cases ETBE and MTBE were added, but this cannot explain the amount of water either, except in a single case where 12% MTBE with the allowable 5% water would result in 0.6 g/kg water in the fuel.

In particular the premium petrol (“super” or Euro-98) does not contain much ethanol, but mainly MTBE and some ETBE instead. Clearly, these chemical components are even better suited to improve the fuel specification of petrol. The admixture of MTBE and ETBE is allowed to a higher fraction than ethanol. This may lead to a lower heating value, as both MTBE and ETBE have lower heating values than the fossil fuel. The reduction of heating value is shown in Table 6.

[4] JRC/Concawe TTW report 2013.

Table 6 The reduction of heating value from the admixture of different components: for example, 4.5% weight admixture of ethanol will result in 4.5% x 0.38% = 1.7% lower heating value.

reduction in LHV	
Ethanol	38.0%
MTBE	18.8%
ETBE	16.0%
FAME	13.7%

The actual petrol composition was determined only later in the project, as the first results showed large and unexplained variation. Based on the last three sets of samples, ethanol has a very constant admixture in Euro-95 of 4.69% with a relative variation of 2.9% (absolute 0.14%). This can therefore not explain the variation in heating values at all, which would be, based on the variation in ethanol admixture, in the order of 0.05%. Likewise, the different Euro-98 samples have similar compositions with MTBE and ETBE which differ only marginally, and the variation in heating value cannot be explained from the bio-admixtures. The origin of the unexpected low heating values of petrol must therefore be in the base, or refinery, fuel component. No proper explanation, for example, from the detailed composition is found as yet.

The current results on fossil components should be compared with the official numbers, for fossil fuels, used in the UNFCCC and EU reporting.[5]

- Petrol 72.0 g/MJ, 44.0 MJ/kg (IPCC 2006: 44.3, RED: 43.0)
- Diesel 74.3 g/MJ, 42.7 MJ/kg (IPCC 2006: 43.0, RED 43.0)

The national numbers take prevalence over the IPCC guideline. In particular the current findings show a deviation for petrol, also after being compensated for the ethanol content. These are derived values, as an assumption on the bio-admixture must be made. The market fuels are analyzed and contain bio-admixture.

[5] P.J. Zijlema, Nederlandse energiedrager lijst en standaard CO2 emissiefactoren, versie april 2015, RVO, and CBS website: www.cbs.nl.

4 Discussions and conclusions

In the discussions regarding fuels and the GHG emissions they produce during combustion there are many stakeholders and different contexts. The stakeholders often have complementary views:

- Consumers would like the fuel, for which they pay per litre, to provide the energy for the propulsion of their vehicle. The relevant unit is therefore MJ/litre. Moreover, they assume the fuel to satisfy specification which will not lead to any damage of the engine.
- The CO_2 emissions are also reported based on fuel sold. Based on weight, the total GHG emissions are therefore related to the carbon content in g/g.
- The total bio-admixture as specified in the Renewable Energy Directive and monitoring requirements in Fuel Quality Directive is based the replacement of fuels according to the energy they supply, as different fuels have different heating values per litre or kilogram. In particular ethanol has a 38% lower heating value (per litre). Therefore the CO_2 reduction of adding 5% ethanol reduces the CO_2 emission by maximal about 3%. The relevant unit for such reporting is the CO_2 emissions in g/MJ.
- Engine manufacturers design and calibrate their engines and fuel systems on the basis of fuel specifications. If these fuel specifications allow for a large variation in composition from bio-admixture with an adapted fossil component, it may lead to reduced engine power, engine malfunctioning and maintenance problems. Some vehicle manufacturers already warn against the use high blends (E10).

The main problem observed in the chemical analyses of the market fuel is the low heating value of petrol and the large variation therein. In particular the summer petrol is affected. Consequently, consumers will get less energy per litre, and it requires more fuel to fulfil the same mobility demand. The large variations are not explained by the bio-admixture itself, but by the quality of the base fuel. The 4.69% ethanol admixture would lead to 1.8% lower heating value in MJ/kg, from 44 MJ/kg down to 43.2 MJ/kg. Instead the heating value (average over summer and winter petrol) is 3.5% lower. This indicates that the effect GHG emission reduction of bio-admixture in petrol is less than half of what is now assumed. For the determination of bio-admixture, and fossil CO_2 emission reduction, the results presented here may have most consequences.

The different conversion numbers used by the stakeholders involved in the Fuel Quality Directive, in particular the effectiveness of bio-admixture based in the metric of g/MJ CO_2 emissions, should be reviewed. This study, carried out by a single chemical laboratory, is only limited in the number of samples and the explanations of the found differences. The most likely cause of the differences found are the properties of the base fuel, or refinery product. It is unlikely that the base fuel, prior to bio-admixture, already satisfies the fuel specification.

The large variation in petrol properties across the samples and the significant change from the currently used values should be examined further. In particular, a monitoring of average heating value over time should be set up. This can be performed by collecting several samples for a single analysis of the heating value and composition, and repeat this once a month.

With a blend of ten samples per month the total number of samples per year would be 120. This will then lead to a statistical sound basis for the the average fuel properties. The sample-by-sample variation in energy content is large and not properly explained by the composition. It is therefore unclear if current findings are systematic for the ethanol admixture at 4.7%.

Table 7 Summary of the findings based on a 50%/50% summer and winter fuel combination, compared with the Statistics Netherlands (CBS) values over 2013.

market fuels with bio-admixture		heating value [MJ/kg]	carbon content [g/MJ]
petrol	Statistics Netherlands 2013	43.20	69.8
	this study	41.65	74.0
diesel	Statistics Netherlands 2013	42.50	72.2
	this study	43.01	72.5

The conclusions of this study regarding the effects of bio-admixture to automotive fuels on CO_2 emissions can be summarised as follows:

- For diesel fuel the findings are in line with previous and international results. About 3% FAME is added to diesel, lowering the heating value by about 0.1%. The numbers are similar to the values currently used for international CO_2 reporting are correct.

- For petrol fuel in contrary, the CO_2 reduction of the bio-admixture can be up to 50% lower due to a reduced energy content of the fuel, on top of the expected energy reduction from the admixture of ethanol. This was the case for most of the summer fuel samples. The winter fuels are more in line with previous findings. On the CO_2 monitoring based on fuel sold the current findings have limited effect as the carbon content is in line with previous results.

- In order to monitor the effectiveness of bio-admixture to fuels, it is recommended to continue the monitoring of petrol fuel properties on a regular basis. This can be used to update emission factors in the future and can provide input to future fuel quality requirements. Moreover, water content is not controlled by current fuel specification, and it may affect the petrol in a more significant manner than found here. It is recommended to monitor diesel fuel properties occasionally.

5 Signature

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A Analyses reports

A.1 Winter 2014-2015

Diesel

Test	Method	Units	001-00	002-00	003-00	004-00	005-00	006-00
Carbon, Hydrogen and Nitrogen	ASTM D5291							
Carbon content		% m	85.5	85.6	86.1	85.4	86.0	85.9
Hydrogen content		% m	13.3	13.2	13.4	13.3	13.3	13.4
Nitrogen content		% m	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
F.A.M.E	EN 14078	% v	7.0	6.3	1.8	6.4	-	-
Heat of Combustion (Net)	ASTM D 240	MJ/kg	42.510	42.415	43.075	42.625	-	-
Density at 15 oC	ISO 12185	g/ml	0.8352	0.8399	0.8344	0.8344	0.8304	0.8328

Petrol (samples 7 and 8 are Euro-98)

Test	Method	Units	001-00	002-00	003-00	004-00	005-00	006-00	007-00	008-00
Density at 15 oC	ISO 12185	g/ml	0.7271	0.7292	0.7405	0.7336	0.7289	0.7337	0.7356	0.7356
Carbon, Hydrogen and Nitrogen	ASTM 5291M									
Carbon content		% m	84.2	83.9	85.2	84.6	83.8	84.3	85.3	85.1
Hydrogen content		% m	13.0	13.1	13.1	12.8	13.1	12.7	12.7	12.7
Nitrogen content		% m	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
Heat of Combustion (Net)	ASTM D 240	MJ/kg	41.910	43.380	41.685	-	-	-	42.090	-
Water	ISO 12937	mg/kg	260	290	240	-	-	-	520	-
Aromatics	ISO 22854	% v	24.2	24.7	27.1	-	-	-	30.9	-

A.2 Winter 2015-2016

Diesel

Test	Method	Units	001-00	002-00	003-00	004-00	005-00
Density at 15 oC	ISO 12185	g/ml	0.8374	0.8405	0.8300	0.8378	0.8362
Carbon, Hydrogen and Nitrogen	ASTM D5291						
Carbon content		% m	86.5	85.3	85.1	86.6	85.2
Hydrogen content		% m	12.7	12.5	12.6	12.5	12.5
Nitrogen content		% m	<0.75	<0.75	<0.75	<0.75	<0.75
Heat of Combustion (Net)	ASTM D 240	MJ/kg	43.130	43.210	43.420	43.205	43.190
F.A.M.E	EN 14078	% v	2.54	0.67	0.06	1.34	2.01
Heat of Combustion (Gross)	ASTM D 240	MJ/kg	45.825	45.860	46.095	45.855	45.840

Petrol (sample 6 is E98, sample 3 is retested, originally 42.665 MJ/kg)

Test	Method	Units	001-00	002-00	003-00	004-00	005-00	006-00
Density at 15 oC	ISO 12185	g/ml	0.7252	0.7275	0.7337	0.7253	0.7257	0.7241
Carbon, Hydrogen and Nitrogen	ASTM D5291							
Carbon content		% m	82.8	83.0	83.8	82.8	82.9	82.6
Hydrogen content		% m	12.4	12.1	12.8	12.4	12.3	12.5
Nitrogen content		% m	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
Heat of Combustion (Net)	ASTM D 240	MJ/kg	41.850	42.445	42.290	42.460	42.645	42.620
Water	ISO 12937	mg/kg	263	238	219	301	287	301
Composition	ISO 22854							
Paraffins		% v	55.2	52.9	57.7	54.6	54.1	54.1
Olefins		% v	8.5	10.3	1.1	8.7	9.3	11.0
Napthenes		% v	6.2	6.3	3.4	6.6	6.4	3.0
Aromatics		% v	23.6	24.3	32.6	23.1	23.9	19.9
Benzene		% v	0.60	0.66	0.76	0.58	0.63	0.40
M.T.B.E.		% v	2.05	1.31	0.58	2.12	1.56	11.84
Methanol		% v	<0.01	<0.01	0.08	<0.01	<0.01	<0.01
Ethanol		% v	4.44	4.74	4.51	4.84	4.69	<0.01
Propanol		% v	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Butanol		% v	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
T.B.A.		% v	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
Ethers (5 or more C atoms)		% v	0.10	0.22	<0.10	<0.10	<0.10	0.15
Other oxygenates		% v	0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ETBE		% v	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Oxygen		% m	2.08	2.08	1.85	2.25	2.09	2.24

A.3 Summer 2015

Diesel

Test	Method	Units	001-00	002-00	003-00	004-00	005-00	006-00	007-00	008-00
Density at 15 oC	ISO 12185	g/ml	0.8382	0.8360	0.8310	0.8253	0.8367	0.8365	0.8328	0.8323
Carbon, Hydrogen and Nitrogen	ASTM D5291									
Carbon content		% m	85.3	84.6	85.5	85.3	85.2	85.0	85.0	83.9
Hydrogen content		% m	12.9	12.8	13.6	13.1	13.7	13.1	13.4	13.2
Nitrogen content		% m	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
F.A.M.E	EN 14078	% v	6.55	0.72	1.13	5.88	4.46	1.31	0.32	5.60
Heat of Combustion (Net)	ASTM D 240	MJ/kg	42.825	43.110	43.155	43.045	42.835	43.190	43.190	42.945

Petrol (samples 10 and 11 are Euro-98, sample 10 later retested: 34.735 MJ/kg)

Test	Method	Units	001-00	002-00	003-00	004-00	005-00	006-00	007-00	008-00
Density at 15 oC	ISO 12185	g/ml	0.7485	0.7384	0.7509	0.7466	0.7409	0.7496	0.7469	0.7446
Carbon, Hydrogen and Nitrogen	ASTM D5291									
Carbon content		% m	83.9	83.4	84.8	84.6	83.8	84.6	83.5	85.1
Hydrogen content		% m	12.4	12.9	12.6	12.4	12.9	12.4	12.6	12.9
Nitrogen content		% m	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
Heat of Combustion (Net)	ASTM D 240	MJ/kg	41.570	40.820	40.260	42.160	41.455	41.925	42.345	42.335
Water	ISO 12937	mg/kg	480	320	330	300	360	500	300	300

Test	Method	Units	001-00	002-00	003-00	004-00	005-00	006-00	007-00	008-00
Composition	ISO 22854									
Paraffins		% v	48.5	50.5	43.0	51.6	51.8	49.4	50.8	50.5
Olefins		% v	6.6	12.9	14.1	2.4	9.0	5.8	3.8	8.4
Napthenes		% v	5.0	5.0	6.3	5.9	5.0	4.1	5.4	4.9
Aromatics		% v	31.3	24.2	31.8	33.6	26.4	33.7	33.1	30.4
Benzene		% v	0.72	0.92	0.74	0.82	0.91	0.68	0.78	0.66
M.T.B.E.		% v	4.06	2.81	0.04	1.95	2.96	1.99	1.51	1.04
Methanol		% v	<0.01	<0.01	<0.01	<0.01	<0.01	0.37	0.61	<0.01
Ethanol		% v	4.56	4.62	4.77	4.59	4.88	4.62	4.78	4.78
Propanol		% v	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Butanol		% v	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
T.B.A.		% v	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethers (5 or more C atoms)		% v	4.09	2.81	<0.10	1.95	2.96	2.02	1.51	1.04
Other oxygenates		% v	<0.10	<0.01	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ETBE		% v	0.03	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01
Oxygen		% m	2.43	2.24	1.76	2.05	2.36	2.27	2.37	1.96

Test	Method	Units	009-00	010-00	011-00
Density at 15 oC	ISO 12185	g/ml	0.7396	0.7419	0.7521
Carbon, Hydrogen and Nitrogen	ASTM D5291				
Carbon content		% m	84.5	83.8	84.5
Hydrogen content		% m	13.0	13.1	12.5
Nitrogen content		% m	<0.75	<0.75	<0.75
Heat of Combustion (Net)	ASTM D 240	MJ/kg	42.550	34.870	41.685
Water	ISO 12937	mg/kg	360	370	890

Test	Method	Units	009-00	010-00	011-00
Composition	ISO 22854				
Paraffins		% v	52.6	46.0	40.5
Olefins		% v	6.5	6.9	6.5
Napthenes		% v	5.7	3.3	3.3
Aromatics		% v	28.6	27.6	34.4
Benzene		% v	0.73	0.50	0.53
M.T.B.E.		% v	1.77	10.94	15.01
Methanol		% v	<0.01	<0.01	<0.01
Ethanol		% v	4.87	0.12	0.07
Propanol		% v	<0.01	<0.01	<0.01
Butanol		% v	<0.01	<0.01	<0.01
T.B.A.		% v	<0.01	0.05	0.06
Ethers (5 or more C atoms)		% v	1.77	15.95	15.26
Other oxygenates		% v	<0.10	<0.10	<0.10
ETBE		% v	<0.01	5.01	0.25
Oxygen		% m	2.14	2.85	2.79