proposed EU year 2000 gasoline volatility specifications

Prepared for the CONCAWE Automotive Emissions Management Group, based upon an Assessment carried out by the Ad-Hoc Gasoline Volatility Group:

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ABSTRACT

A CONCAWE study identified the proposed flat maximum RVP limit across Europe to be of greatest concern within the gasoline volatility specification in the year 2000 EU Draft Fuels Directive. The 60 kPa RVP defined for a six month summer period would lead to problems with regard to driveability and exhaust emissions during intermediate seasons and safety requirements in the more extreme Nordic countries. A flat RVP would result in unbalanced evaporative HC emissions across Europe.

The report concludes that a constant RVP limit for Europe is not practical due to the widely varying summer temperatures. It provides examples for adjusted RVP limits which will provide low but balanced evaporative HC profiles across Europe. Geographically and seasonally adjusted volatility specifications are recommended - an approach which has been applied historically to ensure safe operation and good driveability.

KEYWORDS

Gasoline volatility, vapour pressure, RVP, TVP, evaporative emissions, HC emissions, cold weather driveability, "in-tank" flammability.

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SUMMARY

This report reviews the emissions, performance and driveability implications of the gasoline volatility specifications proposed in the EU year 2000 Draft Fuels Directive. The proposed new RVP limit is identified as the key area of concern and so is the principal focus of the report. Historically, gasoline RVP limits have been set on a geographic and seasonal basis in order to ensure safe operation and good vehicle driveability during both hot and cold weather conditions. The new EU proposal is for a constant 60 kPa RVP limit across all European countries over an extended summer season from April to September.

The report identifies that such a simple proposal is not practical and is likely to result in an increase in vehicle driveability problems in colder countries, particularly during intermediate seasons. Review of in-tank fuel/air vapour mixtures further shows that for intermediate seasons in the more extreme Nordic regions, the EU proposed maximum RVP limit is actually close to or at the minimum safety requirement. It is also identified that reducing volatility during cold conditions can result in an increase in vehicle exhaust emissions which would be counter to the EU objectives.

The intent of the EU limit on RVP was to reduce evaporative HC emissions. It is shown in this report that evaporative HC emissions are a function not only of RVP but also of temperature and fuel system hardware. A constant RVP limit independent of temperature would produce unbalanced evaporative HC emissions with the highest levels in the hottest climates. Setting RVP limits on a temperature related basis would produce a more balanced evaporative HC emissions profile across Europe. Examples are given to show that this approach can achieve the target levels of evaporative HC reduction while avoiding the potential vehicle problems highlighted above. Further work would be needed to identify the optimum RVP limits for each country.

It is concluded that a constant RVP limit for Europe is not practical and that the proposed six month summer season is too long. The target levels of HC emission reduction could be achieved without potential vehicle performance problems by specifying RVP limits and seasonal periods according to climatic variations.

1. INTRODUCTION

The EU Commission has proposed a draft directive on fuels covering environmental specification items for implementation in the year 2000. For gasoline, this includes volatility limits on maximum Reid Vapour Pressure (RVP) and minimum E100 and E150. It is understood that the reason for the new limits is to reduce ozone levels by reducing evaporative and exhaust HC emissions. The limits proposed are as follows:

RVP (1 April - 30 September)	60.0 kPa max.
E 100ºC	46.0% v/v min.
E 150ºC	75.0% v/v min.

Historically (most recently in the CEN specification) volatility limits have always related to climatic and seasonal variations, in order to control hot and cold weather driveability. The proposed EU RVP limit is intended to control evaporative emissions, which will also vary with climate and season. CONCAWE's Automotive Emissions Management Group felt that the proposed single, pan-European volatility limit could possibly lead to increased driveability malfunctions and increased exhaust hydrocarbon emissions in some countries during the early and late part of the defined summer period. Therefore, an ad-hoc group was established to review the impact of the proposed EU volatility specification.

The ad-hoc group has reviewed all volatility related aspects including vehicle evaporative emissions, cold weather driveability and resulting effects on emissions as well as potential safety issues, such as "in-tank" flammability. The report has focused mainly on the proposed RVP reduction since this is the most significant of the volatility specification changes in the fuel directive proposal. The importance of changes in RVP in relationship to the True Vapour Pressure (TVP) of gasolines has also been considered. Since the proposed specification limits are for the year 2000, trends in vehicle population with respect to the foreseen changes in technology, e.g. fuel injection systems have also been provided.

2. THE INFLUENCE OF RVP ON VEHICLE EVAPORATIVE EMISSIONS

Evaporative emissions vary with both ambient temperature and gasoline volatility. CONCAWE has studied the relationships in some detail (Report 90/51 "The effects of temperature and fuel volatility on evaporative emissions from European Cars") and has developed equations to predict hot-soak and running loss emissions (but not diurnal emissions) in terms of RVP and ambient temperature.

The following equation was developed to predict total daily losses (TDL) from an "average" European car:

$$\ln(TDL + 0.01) = -0.609 + 0.0227 * RVP\ (kPa) + 0.0928 * T\ (^{\circ}C)\quad g/day$$

This equation was developed for late 1980s vehicles, mostly equipped with carburettors and without evaporative control systems. However, although the absolute mass emission may not be correct for modern vehicles, the relative effects of RVP and temperature are unlikely to have changed significantly, so the equation should still be valid to predict RVP and temperature effects. Additionally it can be assumed that the equation indicates the amount of vapour that the control systems in modern carbon canister equipped cars have to cope with. The equation is especially useful since comparisons of RVP effects on evaporative emissions are investigated in this section.

Vehicles are currently designed to meet the evaporative emissions limit on a reference fuel of 60 kPa at a test temperature of 25 (+/- 5) ºC. For these conditions the above equation gives TDL of 21 g/day. Ideally the mass of vapour which an evaporative control system has to deal with should be constant under all operating conditions. This can clearly only be achieved if RVP levels are varied to suit climatic conditions, as is the case now. Thus 20 g/day maximum is a reasonable target for other RVP/temperature combinations within Europe.

To assist in proposing RVP limits for Europe which will give a more constant level of emissions, a spreadsheet model has been developed based on the above equation. This has been used to predict monthly average TDL for the different combinations of RVP and temperature found around Europe. Ambient temperature data has been taken from a UK Meteorological Office publication (Met.056c), and has been used to develop temperature distribution models for each month in each country or region. Many countries have been sub-divided into climatically different regions, e.g. north and south UK, where "north" comprises Scotland and Northern Ireland. These regions have been combined on a population weighted basis to predict mean emissions for the country. Generalised Gaussian distribution functions have generally been used, but where the distribution is asymmetric, a "skew factor" has been applied.

Calculations have been carried out for most European countries, and four examples are included in this report, Sweden, Germany, UK and Portugal representing North, Central and South Europe respectively. For each country **Chart 1** shows the different seasonal RVP specifications considered, including the current CEN classes, the proposed EU directive limit of 60 kPa from April to September (example 1) and a number of other RVP/month combinations (example 2,3...). **Chart 2** shows the annual average emissions for these RVP/month combinations in various climatic regions of the country and (population weighted) for the whole country. It also shows the average daily emissions over the year for the various RVP/month combinations and the percentage change relative to their current specification. Finally **Chart 3** shows the variation in TDL by month over the year for the various RVP/month specifications. As discussed above, the ideal should be a constant level of TDL below 20 g/day in all countries and all months.

Reference to the monthly TDL charts shows there is currently a variation from 5 g/day for German or Swedish winter, to 25 g/day for Portuguese summer. Considering the proposed target of 20 g/day max. TDL, this is already achieved in Sweden for all months with current RVP limits. Example 2 shows that further reduction to 70 kPa in summer (equivalent to Swedish Class 2 gasoline specification) gives further reduction to 15 g/day except for July. In Germany the current limits are adequate to meet the 20 g/day target, a reduction to 60 kPa for a short summer period (June-August) would reduce TDL to below 15 g/day. The UK currently only exceeds 20 g/day in September. TDL could be easily reduced to 15 g/day as in example 2 with a 70 kPa limit during June-August and 85 kPa intermediate limits in May and September. For Portugal, the target of 20 g/day can be easily achieved with 60 kPa limit from June-September and intermediate 75 kPa limit in April-May and October-November.

These examples show how this model can be used to optimise RVP specification limits to give relatively constant evaporative emissions across Europe. The CONCAWE proposals are only first attempts to do this, and more detailed study is needed to develop optimum specifications. However it is clear that a flat 60 kPa limit is not appropriate, since adjusted RVP limits and - in most countries - a shorter summer period together with intermediate seasons will give better control of evaporative emissions.

Figures 2.1, 2.2 and **2.3** show the variation in annual average TDL across all European countries over the six-month April - September summer period with respectively:

- current CEN volatility limits (**Figure 2.1**)
- EU draft Directive proposed limits (**Figure 2.2**)
- alternative limits optimised by RVP/month as described above and given in **Table 3.1** (**Figure 2.3**)

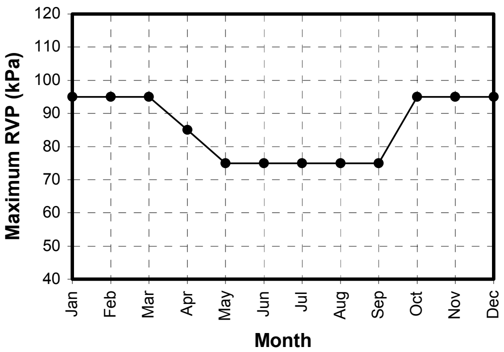
These European data are compared with equivalent data calculated for the USA, assuming use of "conventional" or "Reformulated" gasoline across the whole country. RVP limits used in these calculations are shown in **Table 3.2**.

These figures show that comparing Europe with USA, there is little difference in average total daily losses. Even with current CEN volatility limits, the European average of 9.1 g/day is below the US "conventional" fuel average of 9.8 g/day, and the spread between countries is similar to the regional spread in USA. **Figures 2.2** and **2.3** show that with "Reformulated gasoline" the US average comes down to 9.0 g/day and the EU proposals would reduce emissions in all countries to an average of 6.5 g/day, with only Greece higher than the US average. The CONCAWE alternative limits would also reduce the EU average to 7.6 g/day, well below the 9.0 g/day US average, with only Greece and Spain higher.

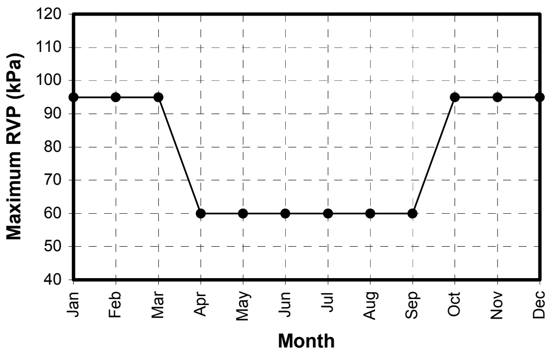
Chart 1 **<u>Sweden</u>** - RVP Specifications

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	95	95	95	85	75	75	75	75	75	95	95	95
Example 1	95	95	95	60	60	60	60	60	60	95	95	95
Example 2	95	95	95	80	80	70	70	70	80	95	95	95
Example 3	95	95	95	80	60	60	60	60	80	95	95	95

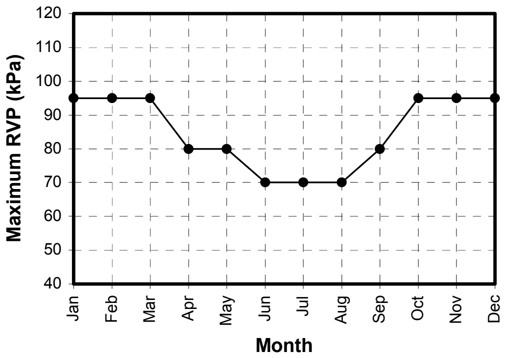
Current



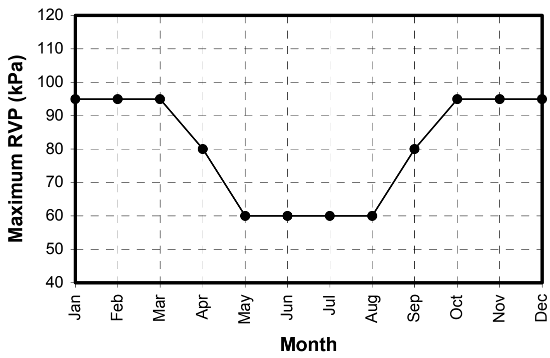
Example 1
Year 2000 RVP



Example 2



Example 3



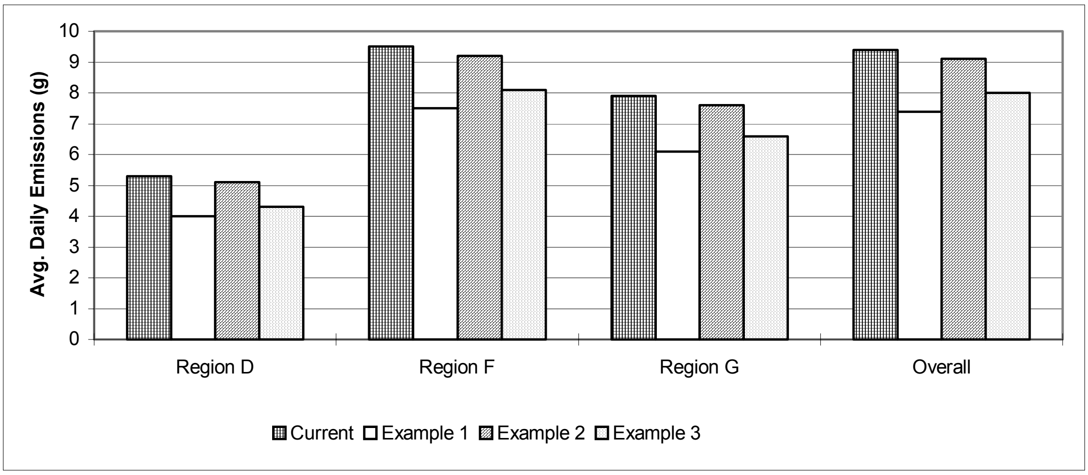
Note Example 1 shows proposed EU Year 2000 RVP
Examples 2 & 3 show proposed alternatives

Chart 2 **Sweden** - Emissions Summary

Total Population: 8322000

Emissions:

Region		Current	Example 1		Example 2		Example 3		Example 4		Example 5	
	% Pop.	TDL/g	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.
Region D	1	5.3	4.0	-24.0	5.1	-4.1	4.3	-18.6				
Region F	97	9.5	7.5	-21.3	9.2	-3.3	8.1	-15.3				
Region G	2	7.9	6.1	-22.4	7.6	-3.5	6.6	-16.4				
Overall		9.4	7.4	-21.3	9.1	-3.3	8.0	-15.4				



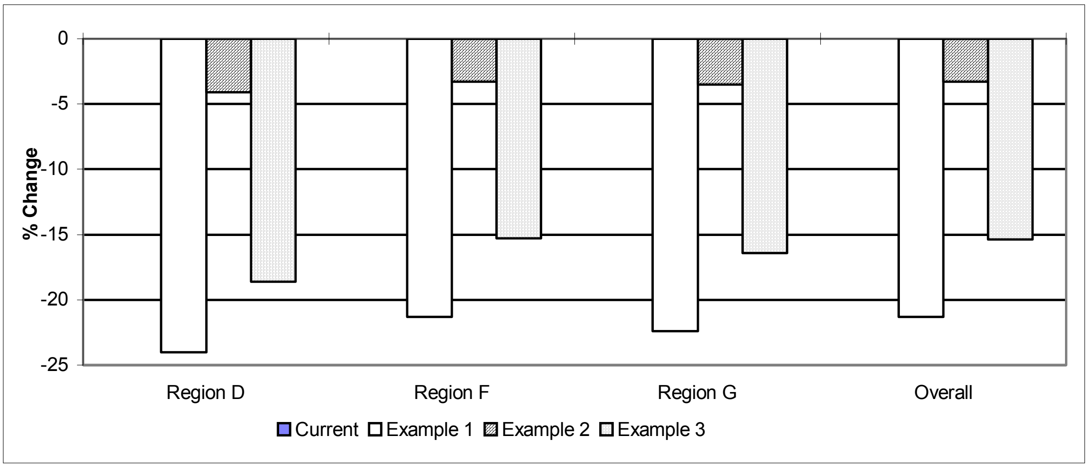
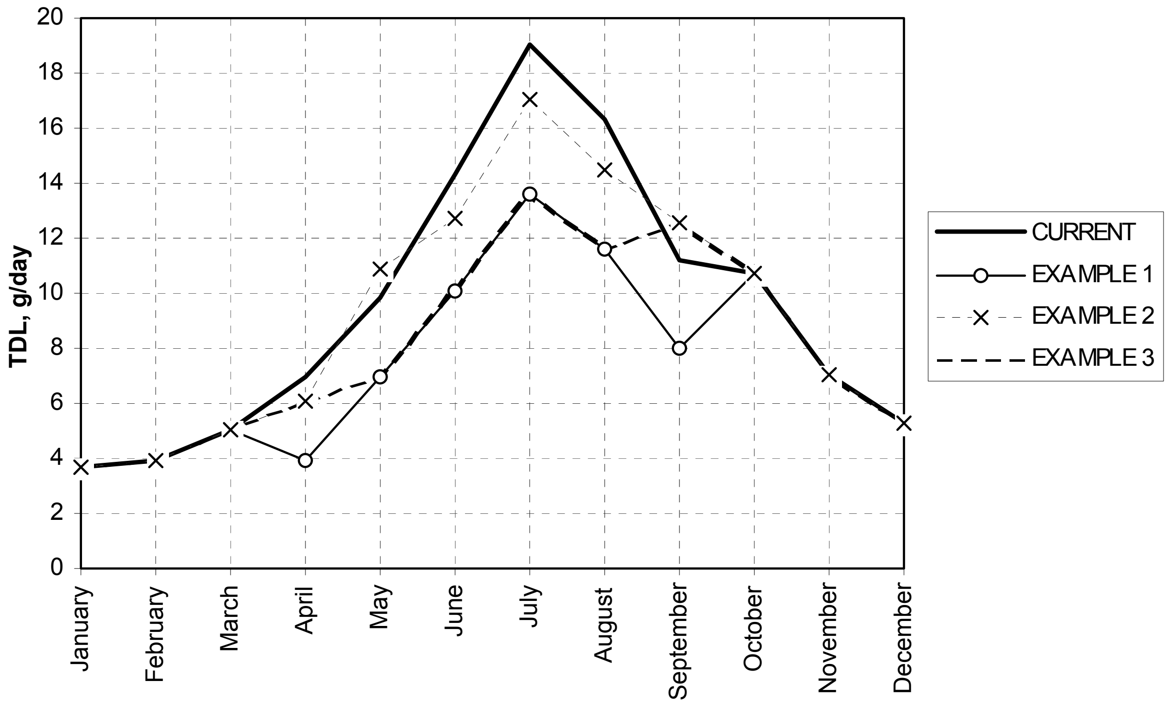


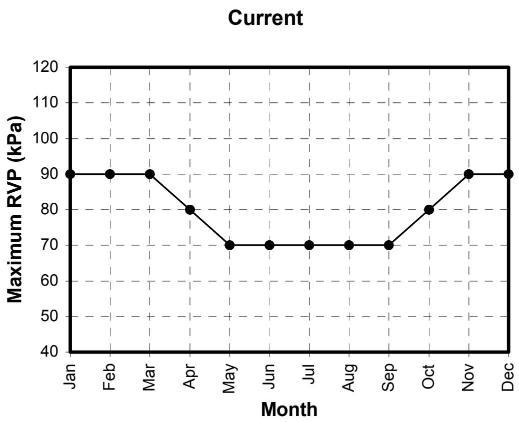
Chart 3 **Sweden** (region F) - TDL Variations with Season

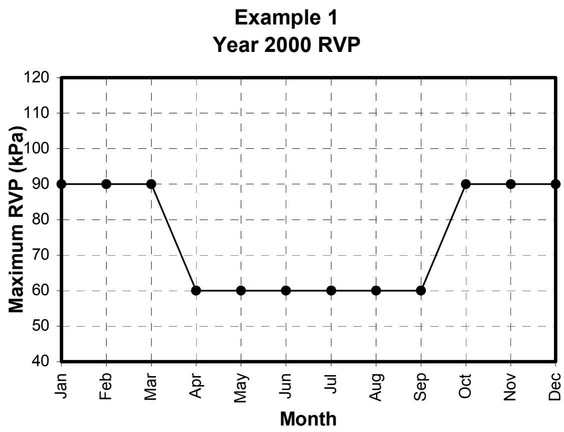


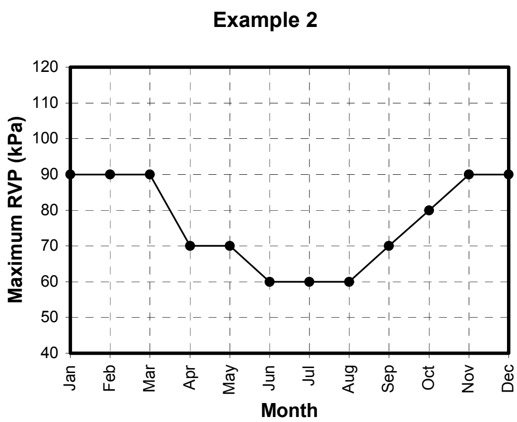
Note Example 1 shows proposed EU Year 2000 RVP
Examples 2 & 3 show proposed alternatives

Chart 1 **Germany** - RVP Specifications

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	90	90	90	80	70	70	70	70	70	80	90	90
Example 1	90	90	90	60	60	60	60	60	60	90	90	90
Example 2	90	90	90	70	70	60	60	60	70	80	90	90







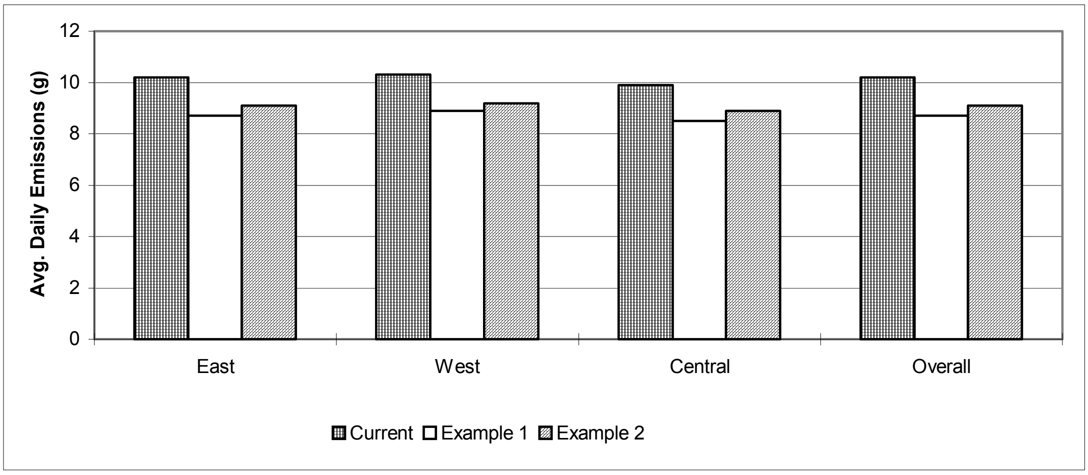
Note Example 1 shows proposed EU Year 2000 RVP
Example 2 shows proposed alternative

Chart 2 **<u>Germany</u>** - Emissions Summary

Total Population: 80000000

<u>Emissions:</u>

Region		Current	Example 1		Example 2		Example 3		Example 4		Example 5	
	% Pop.	TDL/g	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.
East	44	10.2	8.7	-14.1	9.1	-10.3						
West	38	10.3	8.9	-13.7	9.2	-10.0						
Central	18	9.9	8.5	-14.2	8.9	-10.3						
Overall		10.2	8.7	-14.0	9.1	-10.2						



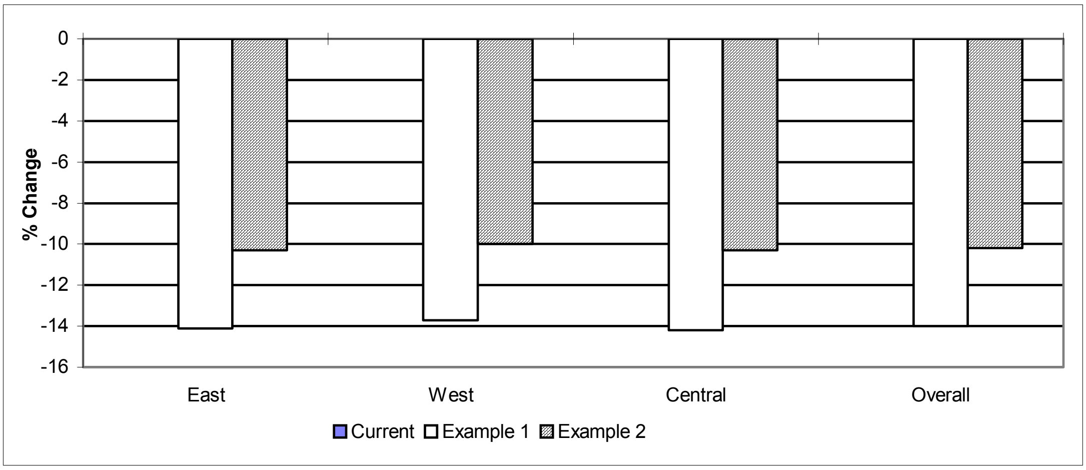


Chart 3 **<u>Germany</u>** (West) - TDL Variations with Season

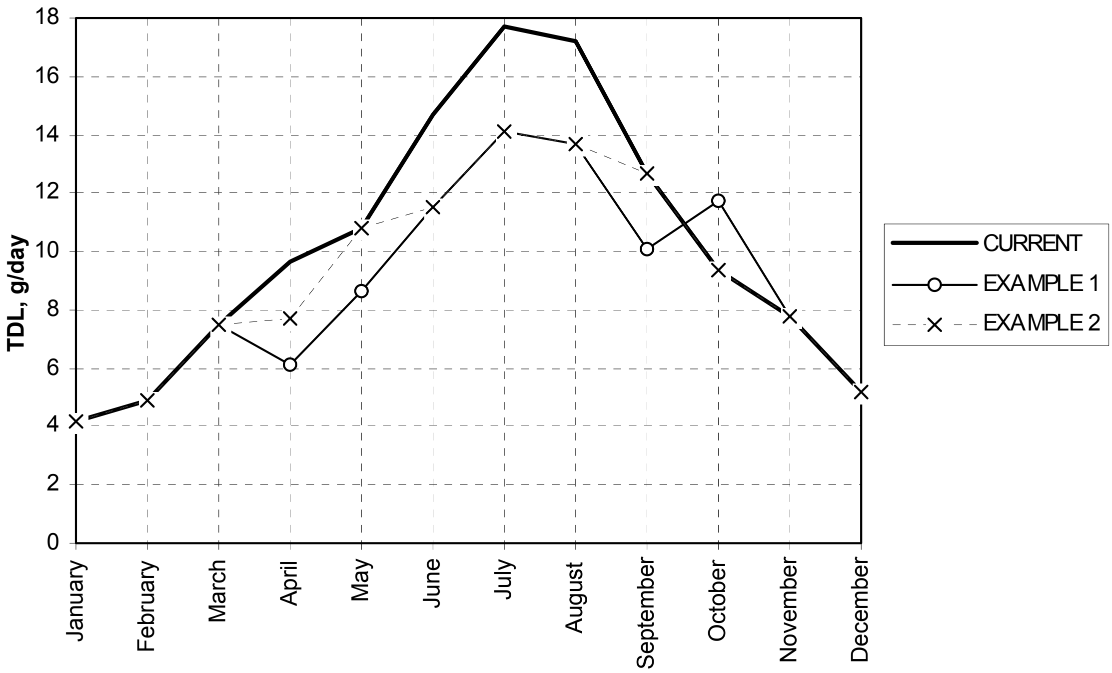
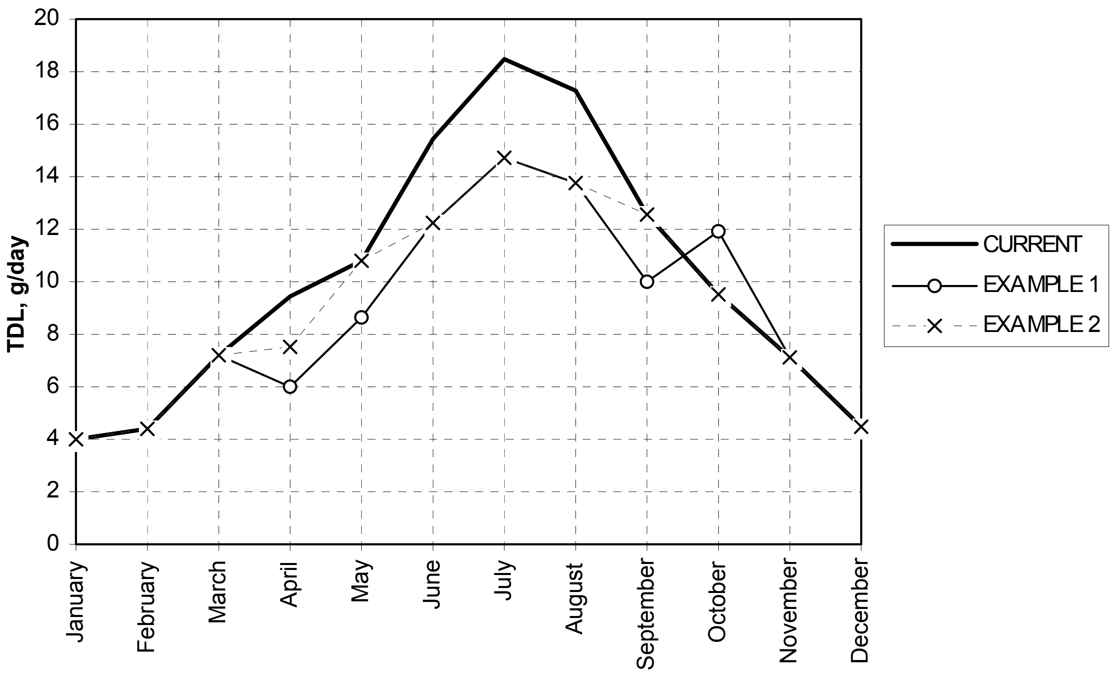


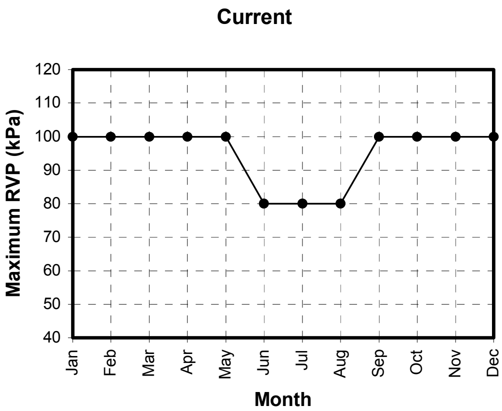
Chart 4 **<u>Germany</u>** (East) - TDL Variations with Season

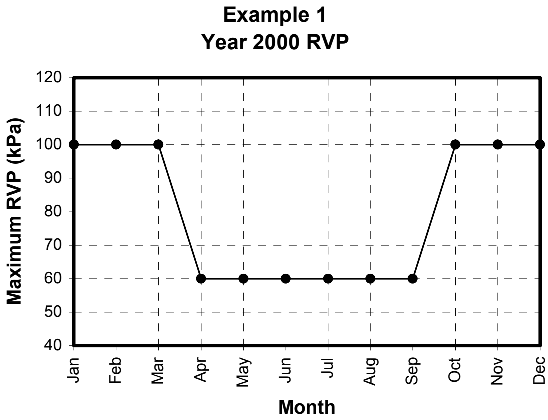


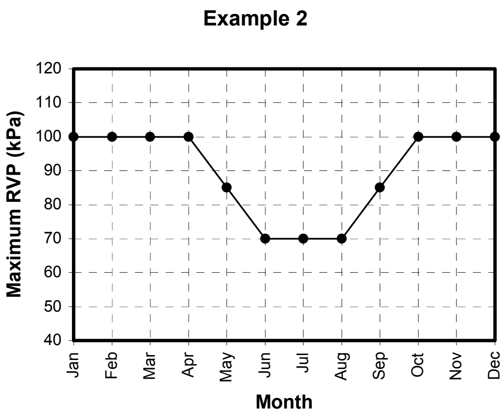
Note Example 1 shows proposed EU Year 2000 RVP
Example 2 shows proposed alternative

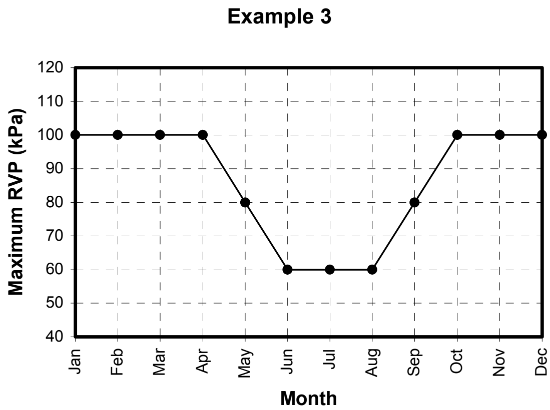
Chart 1 **United Kingdom** - RVP Specifications

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	100	100	100	100	100	80	80	80	100	100	100	100
Example 1	100	100	100	60	60	60	60	60	60	100	100	100
Example 2	100	100	100	100	85	70	70	70	85	100	100	100
Example 3	100	100	100	100	80	60	60	60	80	100	100	100









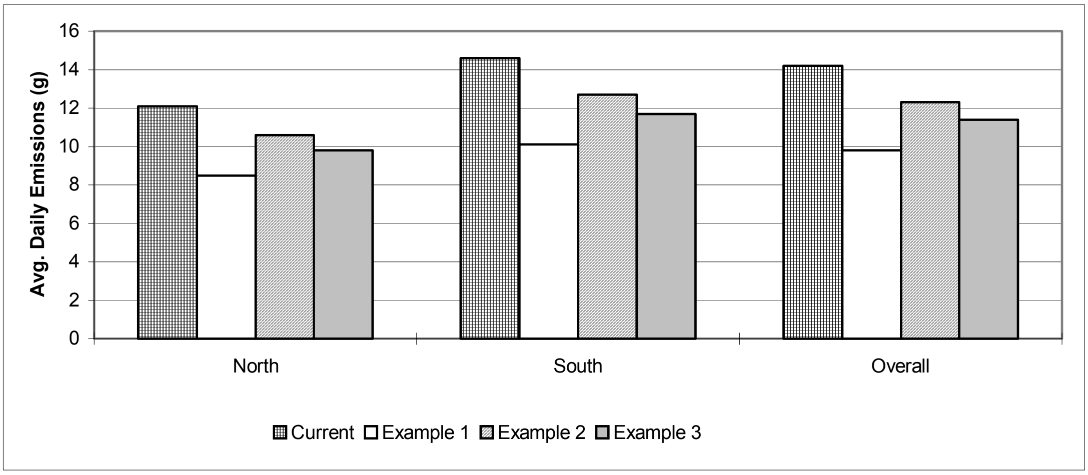
Note Example 1 shows proposed EU Year 2000 RVP
Examples 2 & 3 show proposed alternatives

Chart 2 **United Kingdom** - Emissions Summary

Total Population: 59039000

Emissions:

Region		Current	Example 1		Example 2		Example 3		Example 4		Example 5	
	% Pop.	TDL/g	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.
North	18	12.1	8.5	-29.8	10.6	-12.5	9.8	-18.9				
South	82	14.6	10.1	-31.1	12.7	-13.0	11.7	-19.8				
Overall		14.2	9.8	-30.9	12.3	-13.0	11.4	-19.6				



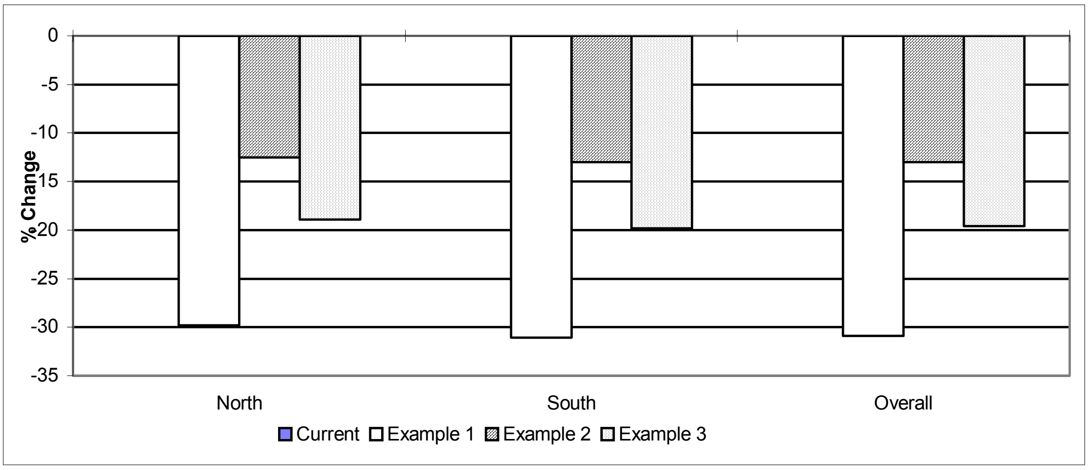
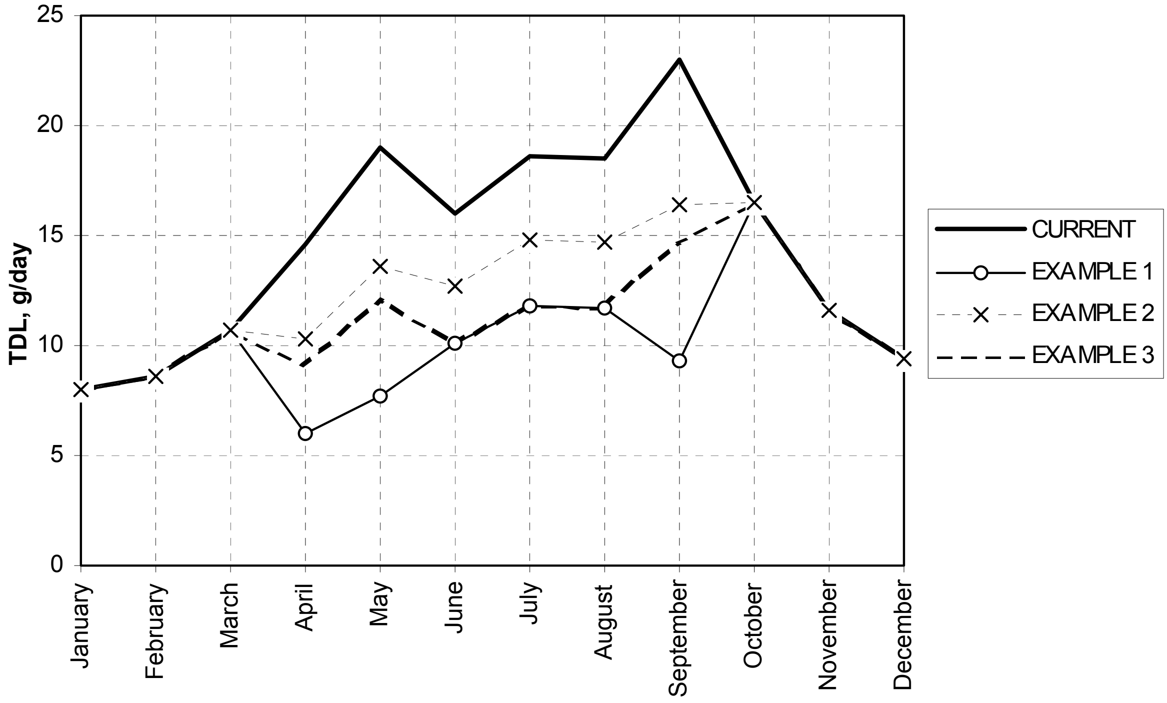


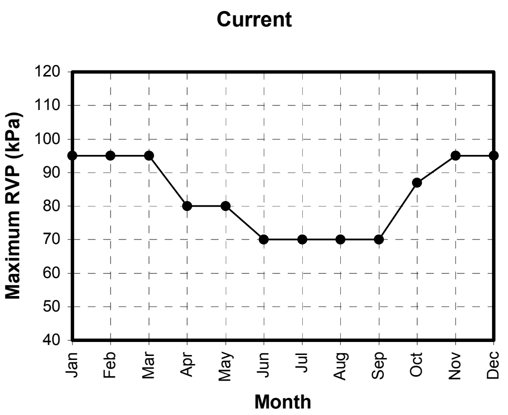
Chart 3 **United Kingdom** (South) - TDL Variations with Season

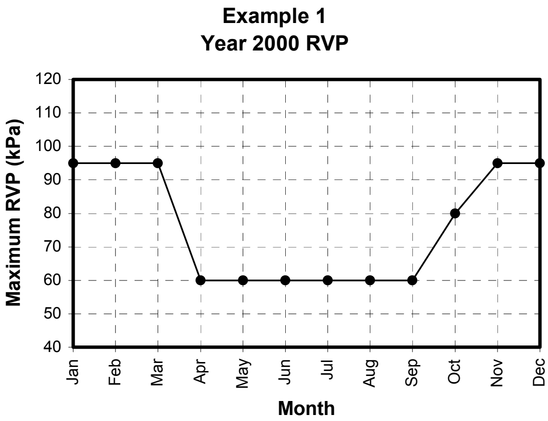


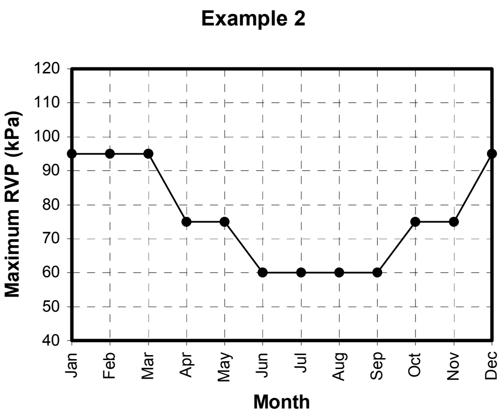
Note Example 1 shows proposed EU Year 2000 RVP
Examples 2 & 3 show proposed alternatives

Chart 1 **Portugal** - RVP Specifications

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	95	95	95	80	80	70	70	70	70	87	95	95
Example 1	95	95	95	60	60	60	60	60	60	80	95	95
Example 2	95	95	95	75	75	60	60	60	60	75	75	95







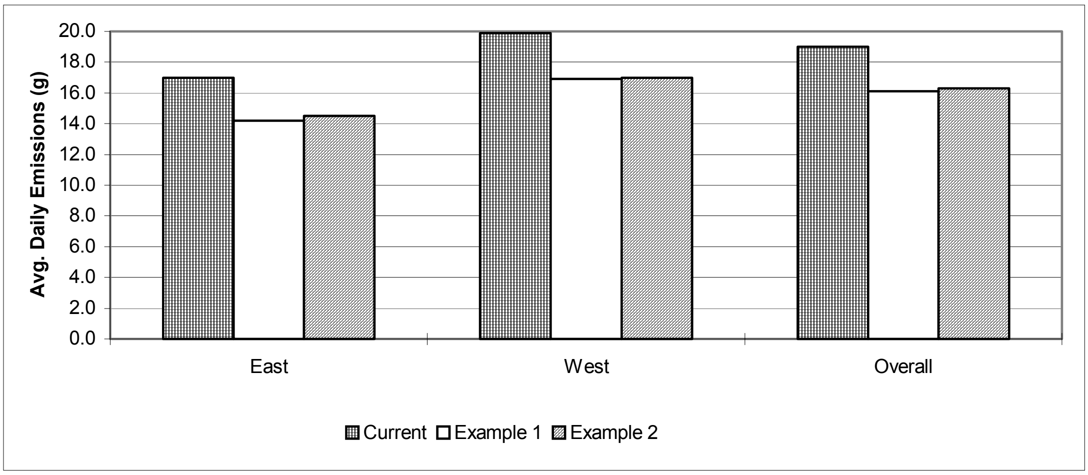
Note Example 1 shows proposed EU Year 2000 RVP
Example 2 shows proposed alternative

Chart 2 **Portugal** - Emissions Summary

Total Population: 11154000

Emissions:

Region		Current	Example 1		Example 2		Example 3		Example 4		Example 5	
	% Pop.	TDL/g	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.	TDL/g	% Diff.
East	30	17.0	14.2	-16.3	14.5	-14.6						
West	70	19.9	16.9	-14.9	17.0	-14.5						
Overall		19.0	16.1	-15.3	16.3	-14.5						



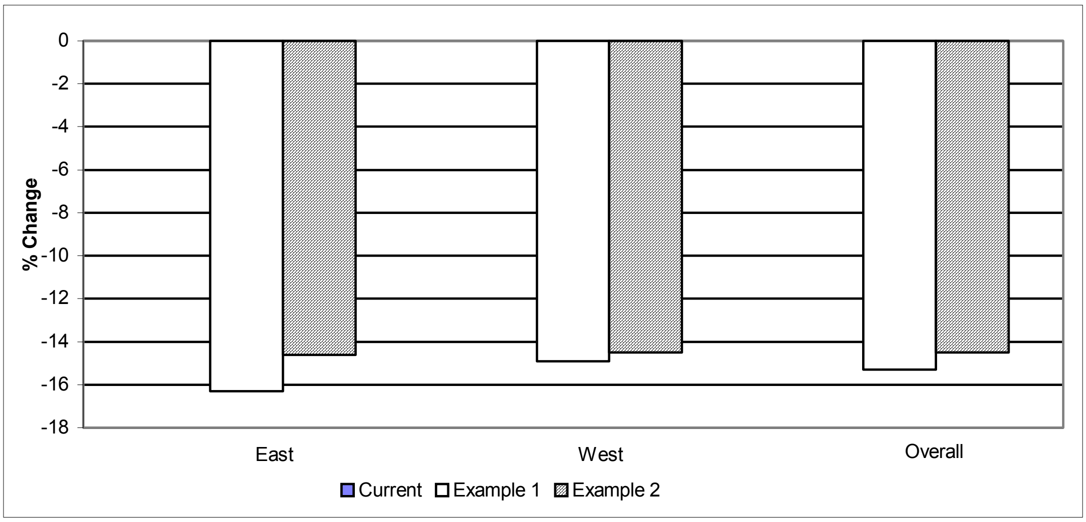


Chart 3 **Portugal** (North) - TDL Variations with Season

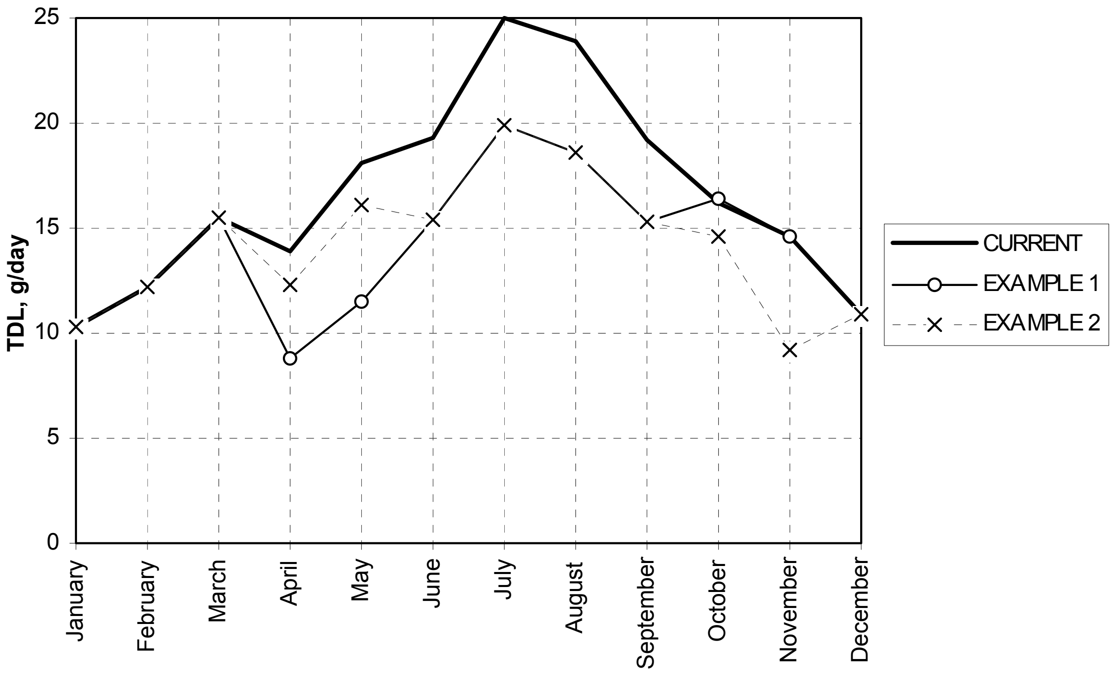
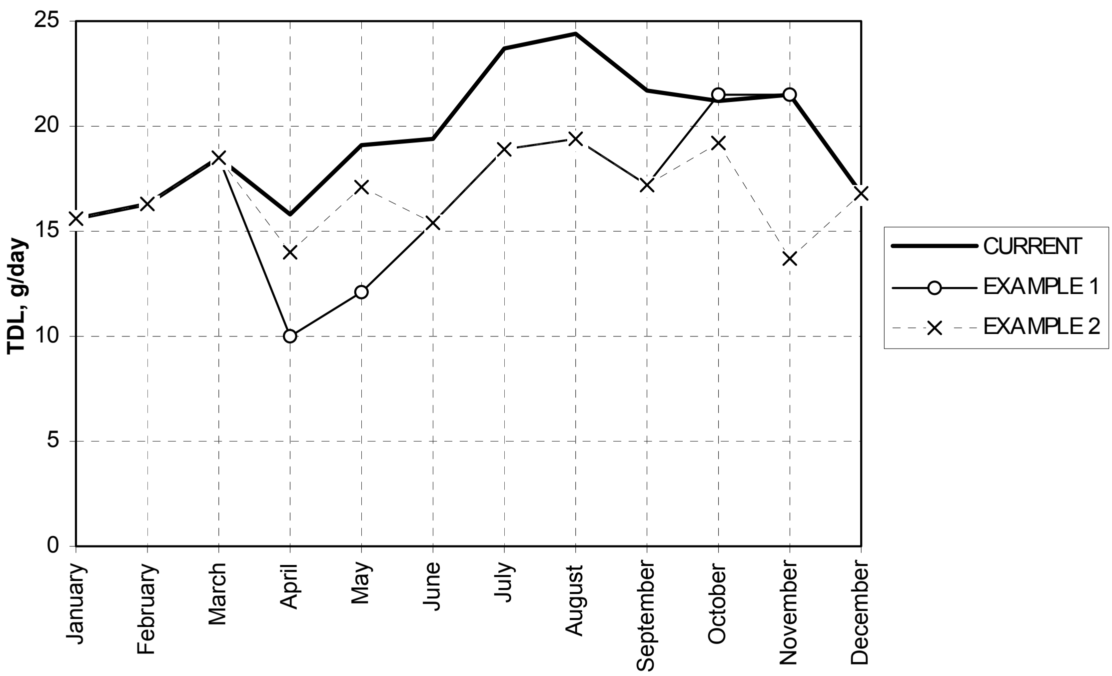
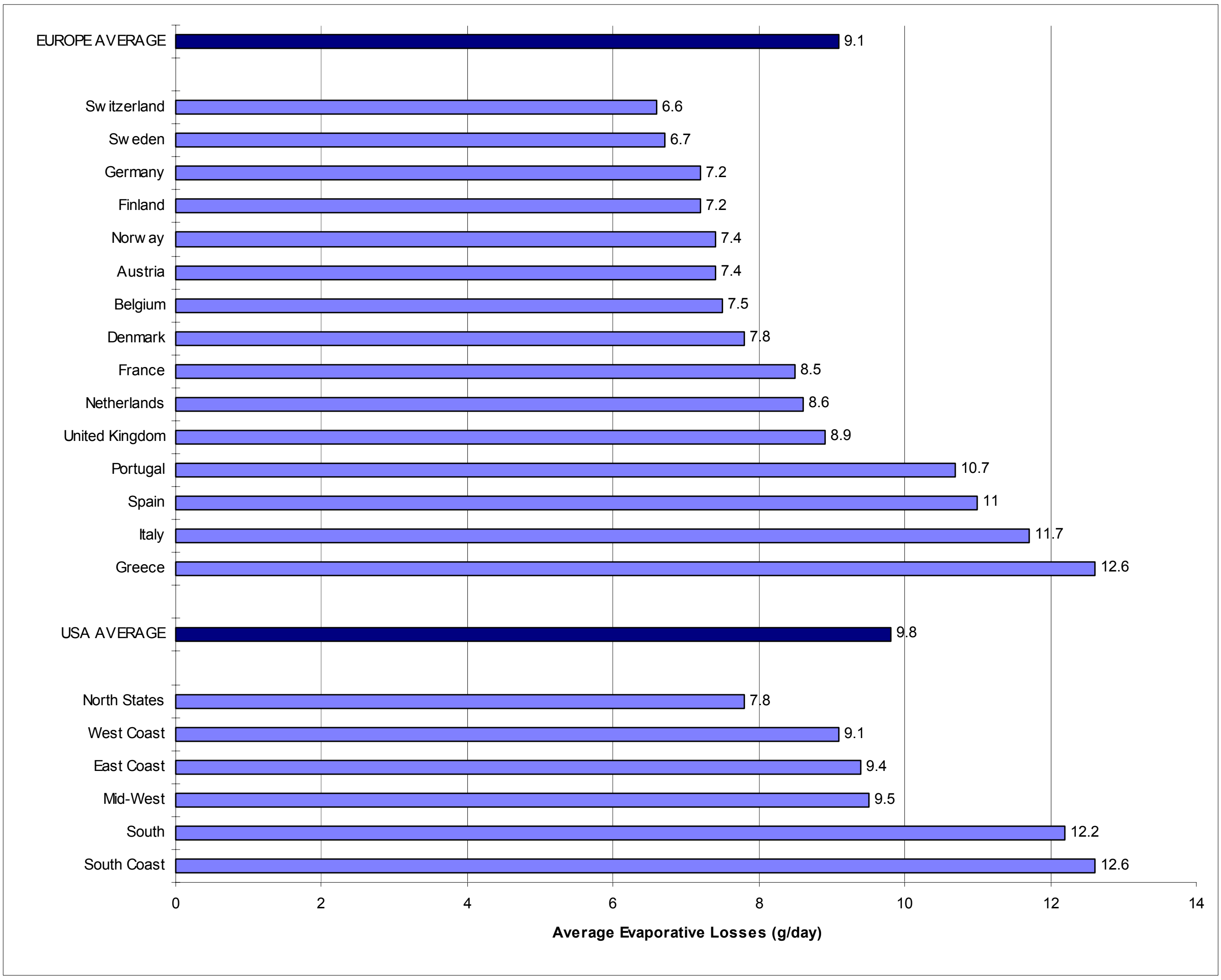


Chart 4 Portugal (South) - TDL Variations with Season



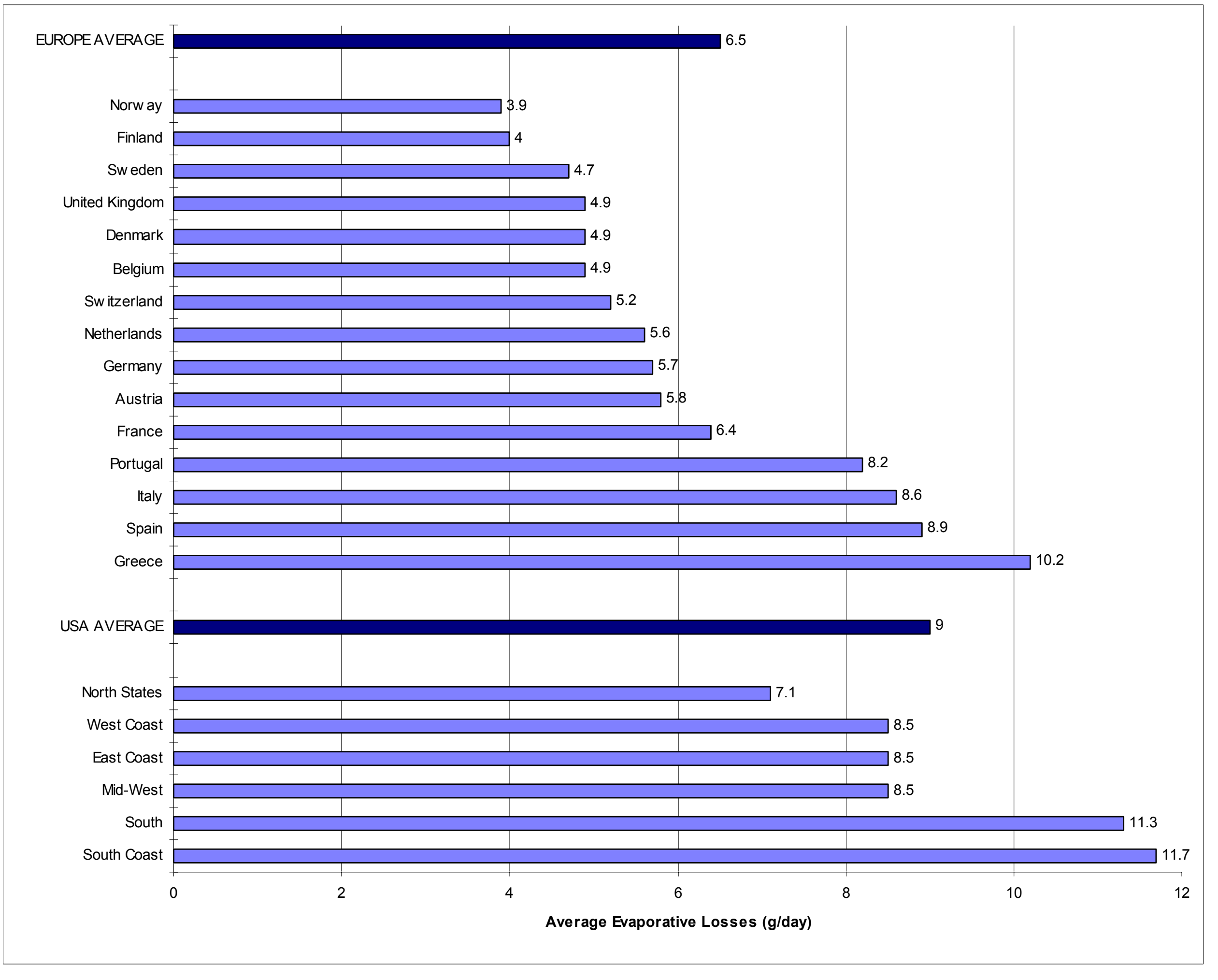
Note Example 1 shows proposed EU Year 2000 RVP
Example 2 shows proposed alternative

Figure 2.1 Calculated Evaporative Emissions for European countries and USA - Based on 1995 EN228 limits for individual countries* (Summer, 1 April to 30 September)



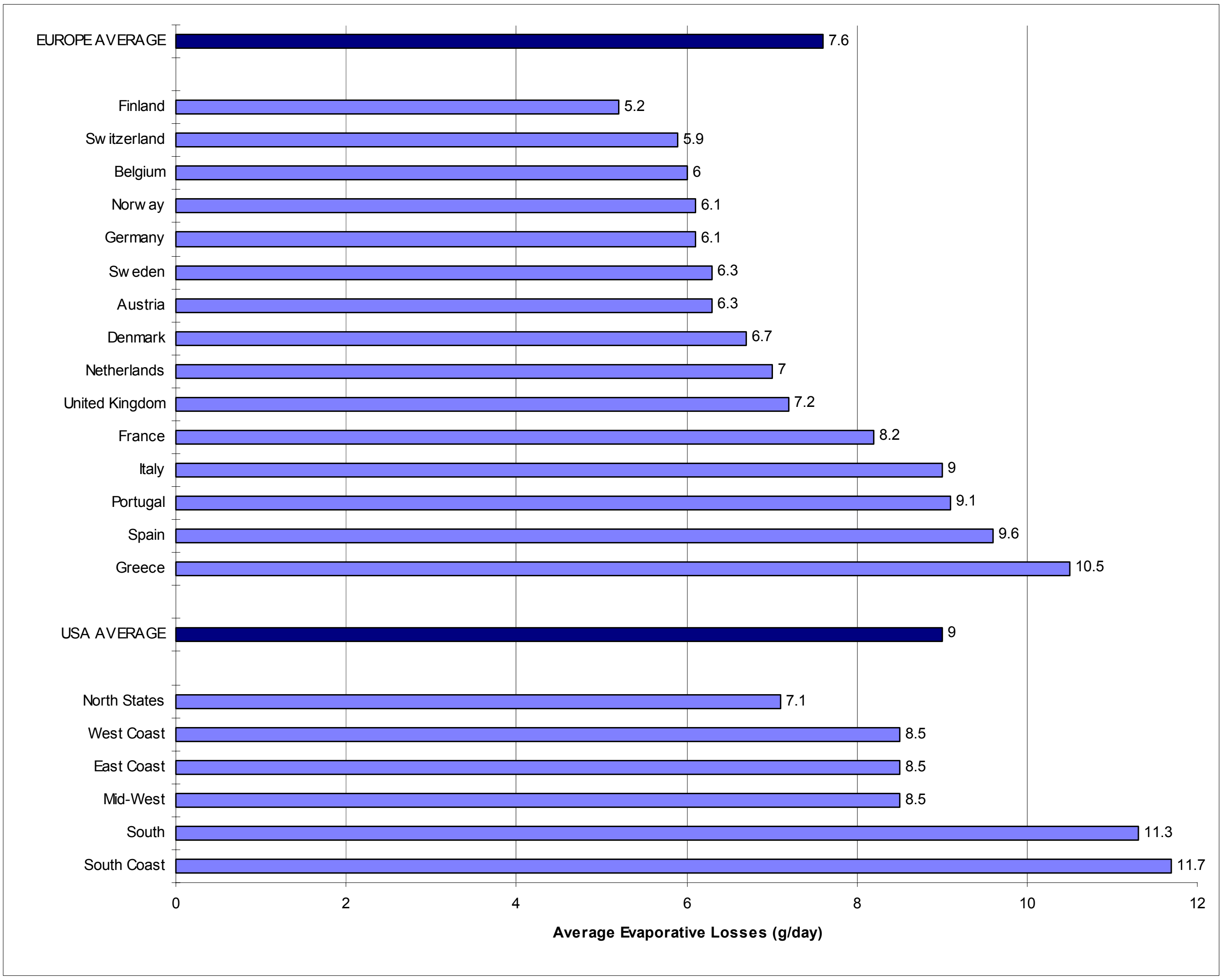
* European and US averages weighted by population. US data based on 1995 specifications for conventional gasoline.

Figure 2.2 Calculated Evaporative Emissions for European countries and USA - Based on proposed year 2000 limits in draft EU fuels Directive* (Summer, 1 April to 30 September)



* European and US averages weighted by population. US data based on 1995 specifications for reformulated gasoline.

Figure 2.3 Calculated Evaporative Emissions for European countries and USA - Based on alternative RVP limits for individual countries* (Summer, 1 April to 30 September)



* European and US averages weighted by population. US data based on 1995 specifications for reformulated gasoline.

3. EVAPORATIVE POTENTIAL FROM STORAGE AND DISTRIBUTION

Potential evaporative losses of gasoline during distribution and storage are best described by True Vapour Pressure (TVP) of the gasoline rather than RVP. TVP depends on the partial pressure of gasoline vapour in the atmosphere at the prevailing ambient temperature. This chapter reviews the effect of changing gasoline RVP on TVP levels and the consequent impact on potential evaporative HC emissions during distribution and storage.

The RVP and average monthly climate data can be used to calculate the True Vapour Pressure (TVP) for each European country, so that the variability in the potential for evaporative losses from storage and distribution can be indicated. The following equation has been used:

$$TVP = RVP \times 10^{((0.000704 \times RVP/100 + 0.01392) \times T + (0.02311 \times RVP/100 - 0.5236))}$$

Where:

T is the monthly average temperature in ºC and

TVP and RVP are in kPa

This equation is taken from the CONCAWE report no. 85/54 which is based on an earlier API nomogram. Data for European RVP and ambient temperatures are summarised in **Table 3.1.**

Table 3.1 compares:

- CEN current regulatory maximum RVP limits based on EN 228
- EU Directive proposed Year 2000 RVP limits and
- alternative CONCAWE proposed Year 2000 RVP limits as discussed in **Chapter 2**. These alternative proposed RVPs are suggestions which would need further refinement.

In addition **Table 3.1** contains the population weighted mean monthly temperatures based on a UK Meteorological Office publication (Met.056c).

- Where alternative seasonal RVP limits are specified for any one month, the average RVP value is taken;
- City Fuels are not included in the data for Finland or for Sweden.

Average RVP levels over a six month (April to September) summer period are calculated from **Table 3.1** and given in **Figure 3.1** comparing the current CEN, proposed EU year 2000 and alternative CONCAWE proposed summer maximum RVP limits. Specification limits are used as it is common practice for the refineries to blend product close to the RVP limit. While the proposed EU year 2000 RVP limits are constant the RVP limits proposed by CONCAWE vary with regard to the ambient temperatures in the individual countries to provide similar levels of evaporative emissions across Europe. Therefore, when compared to the EU 2000 limits, the CONCAWE proposed limits are generally substantially higher in countries with lower ambient temperatures.

True Vapour Pressure values calculated according to the above mentioned equation are plotted in **Figure 3.2**. The difference between the impacts of the current CEN and proposed EU specifications is even more pronounced in this figure where TVP values of current CEN, proposed EU Year 2000 and CONCAWE proposed maximum TVPs limits are compared. **CONCAWE proposed RVP limits provide a more consistent average TVP level** since the EU proposed constant maximum RVP limit does not take into account geographical and seasonal differences.

While TVP describes the evaporative potential from fuel storage and distribution, it is important to remember that actual HC emissions will be linked to the degree of containment of the gasoline storage and supply systems in each of the countries concerned. Stage I controls are already legislated across Europe and eight of the 15 EU countries have introduced or will introduce Stage II vapour recovery to control emissions during vehicle refuelling.

Figure 3.3 shows the maximum RVP and TVP data for conventional and reformulated gasoline (RFG) for the different regions of the USA for the six month summer period which were calculated from RVP and temperature data in **Table 3.2**. The summer TVP data compare well with those shown for Europe when taking the CONCAWE approach. They range for the USA from 36 to 41 kPa (conventional gasoline) and 33 to 39 (RFG) respectively, and for Europe from 33 to 40 kPa.

When combining the regions in the USA and in Europe to three main areas (South, Central and North) the major climatic seasonal differences are adequately covered. On this basis TVPs are compared in **Figure 3.4**. This comparison shows that the TVPs based on both the EU 2000 maximum RVPs and the proposed CONCAWE maximum RVPs are below those for all USA areas for conventional gasoline. When compared with TVPs for US RFG, the resulting TVPs from the proposed CONCAWE RVPs are very similar. Again due to the fact that the EU 2000 proposal does not consider ambient temperature differences, the TVPs for the EU proposal are especially low for central and northern Europe.

The review of maximum True Vapour Pressure levels for the European countries leads to the conclusion that climate adjusted maximum RVP limits will provide consistent average TVP levels across Europe. These levels would be below the TVP levels for US conventional gasoline or at a similar level as for US reformulated gasoline when comparing main areas of both the USA and the EU.

Table 3.1 Maximum RVP limits (kPa) according to CEN specification and proposed EU and CONCAWE Year 2000 limits. Population weighted mean temperature by month (°C)

Country/Month			J	F	M	A	M	J	J	A	S	O	N	D
Austria	RVP	CEN Spec.	90	90	90	80	70	70	70	70	70	80	90	90
		EU 2000	90	90	90	60	60	60	60	60	60	80	90	90
		CONCAWE 2000	90	90	90	80	60	60	60	60	70	70	90	90
	Mean Temperature		-2.7	-0.9	4.1	9	13.5	16.8	18.8	18	14.9	9.2	3.8	-0.6
Belgium	RVP	CEN Spec.	95	95	95	87	80	80	80	80	80	87	95	95
		EU 2000	95	95	95	60	60	60	60	60	60	87	95	95
		CONCAWE 2000	95	95	95	70	70	70	70	70	70	87	95	95
	Mean Temperature		0.3	2.2	4.3	7.8	11.2	14.7	15.6	15.5	13.8	9.7	4.8	1.7
Denmark	RVP	CEN Spec.	95	95	90	90	80	80	80	80	90	90	95	95
		EU 2000	95	95	90	60	60	60	60	60	60	90	95	95
		CONCAWE 2000	95	95	95	80	80	60	60	60	80	80	95	95
	Mean Temperature		0.1	-0.2	2.1	6.5	11.2	14.7	17	16.8	13.8	9.3	5.2	2.52
Finland	RVP	CEN Spec.	100	100	100	100	100	80	80	80	100	100	100	100
		EU 2000	100	100	100	60	60	60	60	60	60	100	100	100
		CONCAWE 2000	100	100	100	85	70	70	70	70	85	100	100	100
	Mean Temperature		-7.3	-7	-4.8	1.6	7.6	13	16.5	15.2	10.1	5.2	-0.1	-3.8
France	RVP	CEN Spec.	90	90	80	80	80	70	70	70	70	80	80	90
		EU 2000	90	90	80	60	60	60	60	60	60	80	80	90
		CONCAWE 2000	90	90	80	70	70	60	60	60	60	80	80	90
	Mean Temperature		4.1	4.9	8.1	10.7	14	17.3	19.2	19	16.6	12.2	7.8	4.9
Germany	RVP	CEN Spec.	90	90	90	80	70	70	70	70	70	80	90	90
		EU 2000	90	90	90	60	60	60	60	60	60	80	90	90
		CONCAWE 2000	90	90	90	70	70	60	60	60	70	80	90	90
	Mean Temperature		-0.3	0.3	4.3	8.6	13	16.3	18.1	17.8	14.6	9.4	4.7	1.1
Greece	RVP	CEN Spec.	80	80	80	70	70	70	70	70	70	80	80	80
		EU 2000	80	80	80	60	60	60	60	60	60	80	80	80
		CONCAWE 2000	80	80	70	70	60	60	60	60	70	70	80	80
	Mean Temperature		8.4	9.1	10.9	14.6	18.7	22.9	25.7	25.6	22.3	18.4	13.9	10.4
Ireland	RVP	CEN Spec.	100	100	100	100	100	80	80	80	100	100	100	100
		EU 2000	100	100	100	60	60	60	60	60	60	100	100	100
		CONCAWE 2000	100	100	100	100	85	70	70	70	85	100	100	100
	Mean Temperature		4.1	4.3	6.1	8.5	11.3	14.2	16	15.9	14	10.6	7.4	5.3
Italy	RVP	CEN Spec.	90	90	80	80	80	75	70	70	75	80	80	90
		EU 2000	90	90	80	60	60	60	60	60	60	80	80	90
		CONCAWE 2000	90	90	80	70	60	60	60	60	70	80	80	90
	Mean Temperature		4.4	6.1	9.3	13.2	17.4	21.2	23.8	23.4	20.2	15.4	10.2	6.4

Note: - Where mixtures are specified for any one month, the average RVP value is taken
- City Fuels are not included in the data for Finland and Sweden

Table 3.1 (cont.) Maximum RVP limits (kPa) according to CEN specification and proposed EU and CONCAWE Year 2000 limits. Population weighted mean temperature by month (°C)

Country/Month			J	F	M	A	M	J	J	A	S	O	N	D
Luxembourg	RVP	CEN Spec.	95	95	95	87	80	80	80	80	80	87	95	95
		EU 2000	90	90	90	60	60	60	60	60	60	87	95	95
		CONCAWE 2000	95	95	95	95	70	70	70	70	70	87	95	95
	Mean Temperature		0.3	2.2	4.3	7.8	11.2	14.7	15.6	15.5	13.8	9.7	4.8	1.7
Netherlands	RVP	CEN Spec.	95	95	95	87	80	80	80	80	80	87	95	95
		EU 2000	95	95	95	60	60	60	60	60	60	87	95	95
		CONCAWE 2000	95	95	95	77	70	70	70	70	70	87	95	95
	Mean Temperature		2	2.1	5.1	8.5	12.3	15.4	17.2	17.2	15	10.6	6.4	3.5
Norway	RVP	CEN Spec.	100	100	100	90	90	90	90	90	100	100	100	100
		EU 2000	100	100	100	60	60	60	60	60	60	100	100	100
		CONCAWE 2000	100	100	100	80	80	80	80	80	100	100	100	100
	Mean Temperature		-5.4	-5.3	-1.2	3.4	8.7	12.7	15.1	14.2	10.2	5.2	0.8	-2.5
Portugal	RVP	CEN Spec.	95	95	95	80	80	70	70	70	70	87	95	95
		EU 2000	95	95	95	60	60	60	60	60	60	87	95	95
		CONCAWE 2000	90	90	90	75	75	60	60	60	60	75	75	95
	Mean Temperature		10.7	11.3	12.8	14.4	16.4	19.4	21.6	22	20.5	17.4	13.9	11.5
Spain	RVP	CEN Spec.	80	80	80	70	70	70	70	70	70	70	80	80
		EU 2000	80	80	80	60	60	60	60	60	60	70	80	80
		CONCAWE 2000	80	80	80	70	70	60	60	60	70	70	80	80
	Mean Temperature		7.7	8.8	11.5	13.7	16.4	20.8	23.6	23.4	20.8	16.1	11.6	8.5
Sweden (N)	RVP	CEN Spec.	95	95	95	95	85	75	75	75	95	95	95	95
		EU 2000	95	95	95	60	60	60	60	60	60	95	95	95
		CONCAWE 2000	95	95	95	80	80	70	70	70	80	95	95	95
	Mean Temperature		-8.5	-8.1	-4.4	1.2	7.2	12.4	15.8	14.2	9.3	3.4	-1.5	-5
Sweden (S)	RVP	CEN Spec.	95	95	95	85	75	75	75	75	75	95	95	95
		EU 2000	95	95	95	60	60	60	60	60	60	95	95	95
		CONCAWE 2000	95	95	95	80	80	70	70	70	80	95	95	95
	Mean Temperature		-1.9	-2.2	0.1	4.9	10.2	14.7	17.6	16.7	12.7	7.8	3.6	0.9
Switzerland	RVP	CEN Spec.	95	95	95	83	70	70	70	70	70	83	95	95
		EU 2000	95	95	95	60	60	60	60	60	60	83	95	95
		CONCAWE 2000	95	95	95	75	75	60	60	60	75	75	95	95
	Mean Temperature		-1.1	0.2	4.1	7.7	11.8	15.3	17.3	16.9	13.9	8.6	3.6	0
UK	RVP	CEN Spec.	100	100	100	100	100	80	80	80	100	100	100	100
		EU 2000	100	100	100	60	60	60	60	60	60	100	100	100
		CONCAWE 2000	100	100	100	100	85	70	70	70	85	100	100	100
	Mean Temperature		4.1	4.3	6.1	8.5	11.3	14.2	16	15.9	14	10.6	7.4	5.3

Note: - Where mixtures are specified for any one month, the average RVP value is taken
- City Fuels are not included in the data for Finland and Sweden

Table 3.2 Ambient temperature (°C) and Maximum RVP (kPa) Limit Data of Conventional and Reformulated Gasoline for the USA

		J	F	M	A	M	J	J	A	S	O	N	D
East Coast	**Av T**	-0.2	-0.1	4	9.7	15.6	20.6	23.6	22.7	19.1	13.6	7.7	1.6
	RVP												
	Conventional	103	103	93	93	62.1	62.1	62.1	62.1	62.1	79	93	103
	Reformulated	103	103	93	93	56	56	56	56	56	79	93	103
Mid West	**Av T**	-1.2	1	4.7	10.6	15.8	21.3	25.3	24.3	19.4	13	4.9	0.8
	RVP												
	Conventional	103	103	93	79	62.1	62.1	62.1	62.1	62.1	79	93	103
	Reformulated	103	103	93	79	56	56	56	56	56	79	93	103
North States	**Av T**	-6.6	-5.4	-0.9	7.1	13.2	19.5	21.8	21	16.1	10	1.9	-4.1
	RVP												
	Conventional	103	103	93	93	62.1	62.1	62.1	62.1	62.1	86	93	103
	Reformulated	103	103	93	93	56	56	56	56	56	86	93	103
South Coast	**Av T**	13.7	14.6	16.9	20.4	23.9	26.6	27.5	27.6	26	21.9	17	14.1
	RVP												
	Conventional	93	93	86	69	62	53.8	53.8	53.8	53.8	79	86	93
	Reformulated	93	93	86	69	56	50	50	50	50	79	86	93
South	**Av T**	8.6	10.2	13.7	18.6	23	27.2	28.7	28.6	25.4	20.3	13.4	9.7
	RVP												
	Conventional	93	93	79	69	62	53.8	53.8	53.8	53.8	69	79	93
	Reformulated	93	93	79	69	56	50	50	50	50	69	79	93
West Coast	**Av T**	8.8	10.4	12.3	14.9	17.8	20.7	23.2	22.6	21.1	17.2	12.7	9.8
	RVP												
	Conventional	93	93	79	79	62	53.8	53.8	53.8	53.8	69	79	93
	Reformulated	93	93	79	79	56	50	50	50	50	69	79	93

Note: Since 1996, a lower limit of 48.2 kPa is required in California for Phase 2 reformulated gasolines.

Figure 3.1 Current CEN RVP limits compared with proposed EU 2000 and proposed CONCAWE 2000 limits on RVP
- 6 month summer averaged maximum RVPs

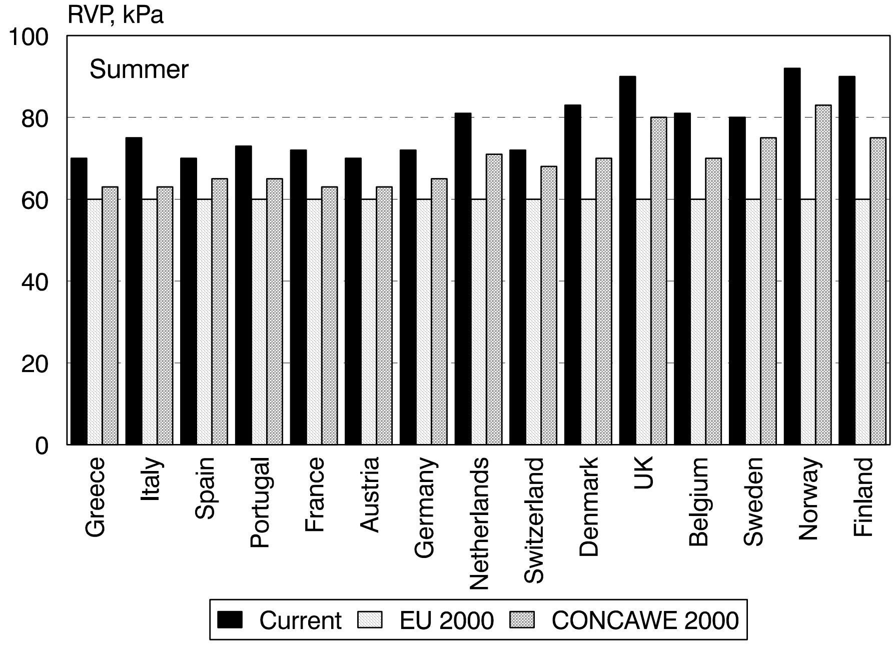


Figure 3.2 Current CEN TVPs compared with proposed EU 2000 and proposed CONCAWE 2000 levels on TVP
- 6 month summer averaged maximum TVPs

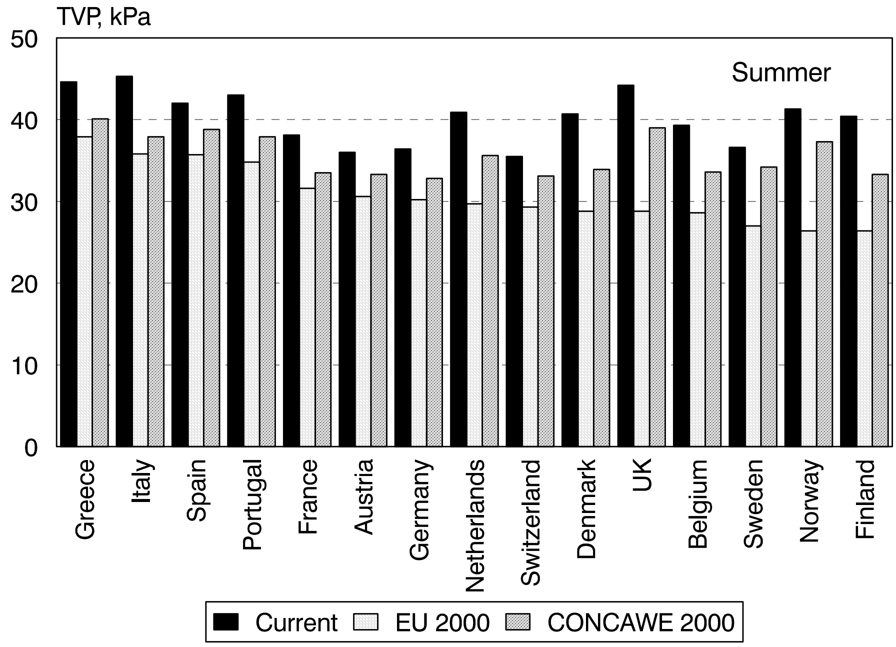


Figure 3.3 Comparison between maximum RVP and TVP data for the USA
- 6 month summer average maximum RVPs and TVPs

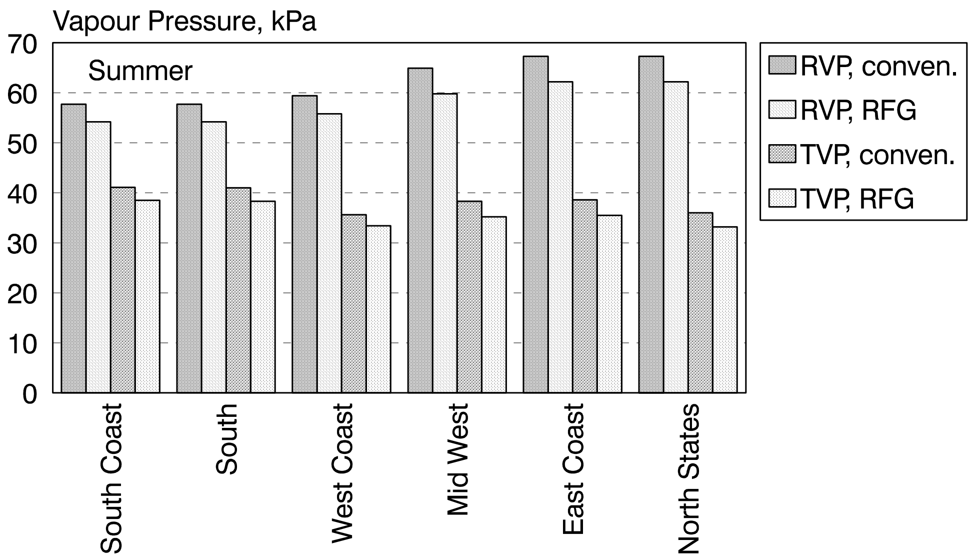
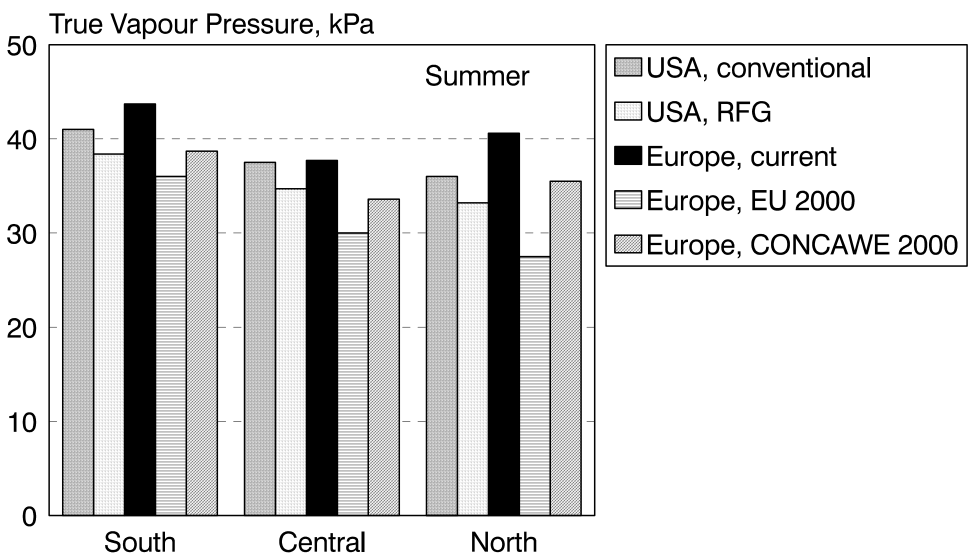


Figure 3.4 Comparison between TVP levels for the USA and current and proposed year 2000 levels for Europe
- 6 month summer average maximum TVP levels for areas



4. COLD WEATHER DRIVEABILITY EFFECTS AND TRENDS IN VEHICLE POPULATION

Cold weather driveability malfunctions are a manifestation of engine misfires or poor combustion which will lead to increased HC emissions, as found in the EPEFE programme. There is a concern that the EU proposed year 2000 single pan-European RVP limit of 60 kPa to be introduced for a six month summer period (April to September) will lead to increased driveability malfunctions during the early and late summer periods, where ambient temperatures in some northern EU countries can be as low as -15°C. The proposed RVP of 60 kPa may have to cater for ambient temperatures (average monthly min/max) ranging from -15ºC in Scandinavia in April to +35ºC in Italy in July.

Cold weather driveability (CWD) is influenced by three principal factors, vehicle technology, ambient temperature and gasoline volatility.

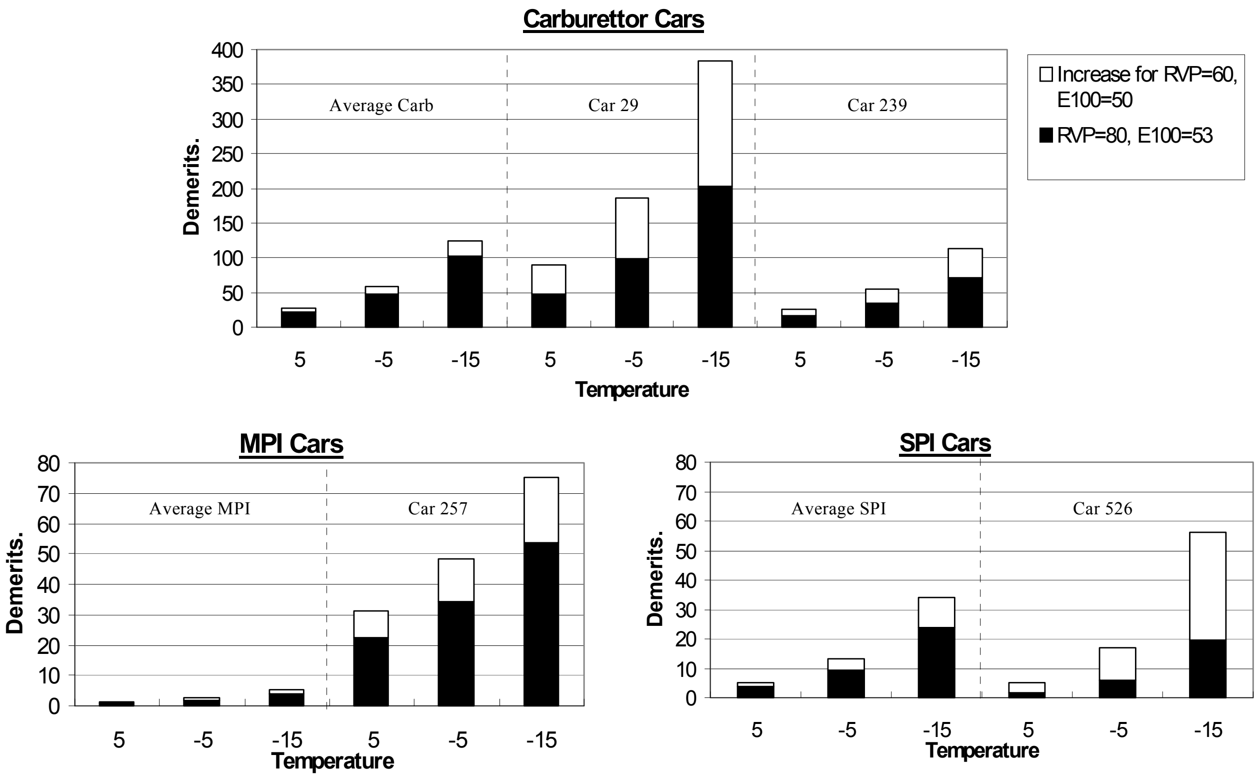
- Vehicle technology has the greatest influence on cold weather driveability. In general, vehicles fitted with carburetted fuel systems have poorer driveability and are more sensitive to changes in volatility than those with single point injection (SPI) which, in turn, are more sensitive than those fitted with multi-point fuel injection.
- Across the range of vehicle technologies, CWD is largely controlled by mid-range volatility (E100). Reducing RVP by 20 kPa (assuming a move from the current class 4 RVP of 80 kPa) equates to approximately 5% butane reduction that would result in an E100 reduction of around 3% v/v. It is this combined effect of RVP and E100 reduction that will lead to increased driveability problems in some countries, at lower ambient temperatures.
- CWD is poorer at lower ambient temperature.

Figure 4.1 illustrates the effect of changing volatility, at different ambient temperatures, on the driveability performance of vehicles with different fuel systems. The effects are greatest for carburetted vehicles, which also exhibit the highest fleet average demerit levels. A decrease in RVP and E100 from 80 to 60 kPa and 53% to 50% v/v respectively, results in a ~25 demerit increase at -15°C. A reduced but significant effect is also seen with single point injection vehicles. It can further be seen that some individual vehicle models in each fuel system category can be a great deal more sensitive to both ambient temperature and volatility compared to the fleet average.

Although all new vehicles sold in Europe are fitted with SPI (Single Point Injection) or EFI (Electronic Fuel Injection), **Figure 4.2** shows that carburetted vehicles will, on average, continue to represent approximately 20% of the European vehicle population in the year 2000. This, combined with a substantial proportion of SPI vehicles in the market, means that a substantial part of the year 2000 vehicle population will remain critical under the proposed EU volatility specifications.

The most effective ways to reduce CWD related problems are to shorten the summer period thus removing the colder months of April and September, and/or set regional volatility limits to take into account climatic and seasonal temperature profiles. It is also recognised, however, that driveability performance could be maintained with an RVP of 60 kPa by increasing mid-range volatility. However, a more stringent E100 specification could cause refinery production problems in some markets and would be a far less cost effective solution.

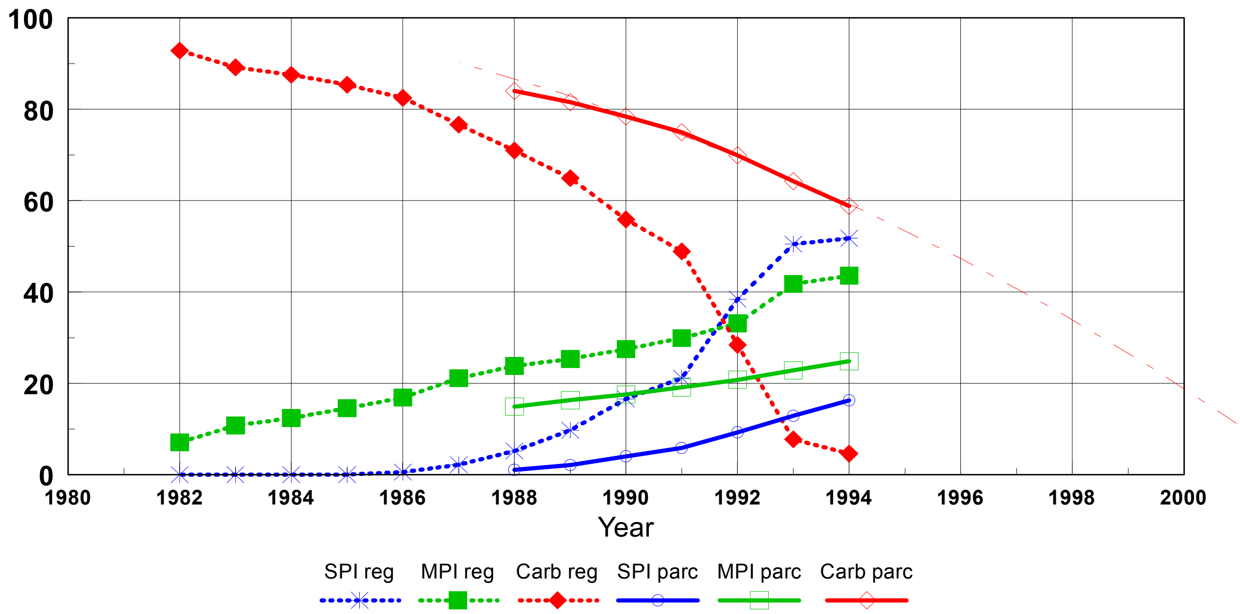
Figure 4.1 Overall implications of proposed volatility change



Note: Temperatures in °C

Figure 4.2 Trends in European Gasoline Fuel Systems

Percentage of fuel systems in new registrations ("reg") and in vehicle parc ("parc")



Note: New registrations/parc at end of each year
A, B, CH, D, E, F, GB, GR, I, NL, P, S

5. VOLATILITY INFLUENCES ON VEHICLE EXHAUST EMISSIONS

In order to assess the influence of volatility on vehicle exhaust emissions three reports were reviewed, the DGMK 513, the API 4533 and the CONCAWE report 93/51.

The objective of the DGMK Project 513 was to investigate the effect of lower gasoline RVPs on the exhaust emissions and evaporative emissions of modern passenger cars at lower ambient temperatures.

The exhaust emission testing was carried out at -7ºC in climate controlled chassis dynamometers using the MVEG driving cycle which determines exhaust emissions from cranking of the engine and does not employ the 40 seconds idle period prior to sampling used in the present ECE+EUDC driving cycle. Eight catalyst and carbon canister equipped European type cars were used which had been manufactured during the years 1989 to 1995. Six of the 8 cars were equipped with multi-point fuel injection (MPI), the remaining 2 cars were equipped with single point injection systems (SPI).

Diurnal and hot soak evaporative emissions were determined using two 1995 model year passenger cars, both equipped with carbon canisters.

Three test fuels were blended close to the average qualities found in the German market with the main variation for RVP at levels of 54, 67, and 85 kPa. E70ºC data of these fuels varied between 24 and 28 %-v/v, E100 was kept constant.

Multiple exhaust emission tests were carried out at -7ºC and led to the following results:

- As with other programmes the main portion of the exhaust emissions occurred during the first ECE15 cycle while the engine was still warming up.
- No significant effects of RVP on CO, NOx and CO2 emissions were found.
- HC exhaust emissions were on average 13% higher (up to 33% for individual cars) on the 54 kPa RVP gasoline compared to the 85 kPa gasoline for those cars equipped with MPI systems, whereas the two cars equipped with SPI showed no significant effect on HC exhaust emissions. The increase in exhaust HC emissions is similar to that described in the CONCAWE report 93/51.

The CONCAWE 93/51 programme, used four catalyst and four non-catalyst cars and found:

- HC exhaust emissions increased by around 300 per cent as temperature was reduced from 25 to -5°C. It was found that HC exhaust emissions decreased with the high volatility fuel (96 *vs.* 61 kPa RVP) in almost all cars by approximately 5 per cent.
- Evaporative emissions were determined at +30 and +15ºC and slightly lower emissions were observed using the lower RVP gasolines. However, the differences were not significant. For both cars tested evaporative emissions were around 0.3 g/test, well below the limit of 2.0 g/test, and no vapour break-through was observed.

The API Report 4533 covers work conducted in 1988 - 90 on the relationship between changes in gasoline RVP and oxygenate content on the level and composition of vehicle emissions at different temperatures (+2 to 27ºC). It used 11 US-type passenger cars from the model years 1981 to 1989 tested according to the FTP-75 test procedure for exhaust and evaporative emissions. The test fuels varied RVP from 48 to 90 kPa, and ethanol, MTBE and ETBE were used as oxygenates together with the hydrocarbon gasolines.

Specific findings from the test work are:

- The effect of changes in RVP on exhaust HC emissions varies with ambient temperature. At 27ºC, exhaust HC decreases with reductions in RVP, whereas at 13ºC reductions in RVP produce a small, but statistically significant increase in exhaust HC emissions. At +2ºC, changes in RVP had no significant effect on exhaust HC
- Changes in RVP had no significant effect on CO exhaust emissions at +2 and 13ºC, but at 27ºC lower CO emissions are observed when lowering RVP from 90 to 69 kPa.
- Gasoline RVP had no significant effect on NOx emissions at ambient temperatures tested.
- Contrary to the result of the DGMK project, lowering gasoline RVP produced a statistically significant reduction both in diurnal and hot soak evaporative losses. The tested US vehicles were of older design with less effective control on evaporative emissions than those tested in the DGMK project. Due to the exponential effect of temperature on true vapour pressure (TVP), the effects are largest at the higher RVPs and the higher ambient temperatures used for testing.

In summary, the test work reviewed indicates that:

- lower RVP fuels tend to increase hydrocarbon exhaust emissions at temperatures which would be found in European intermediate seasons
- there is no effect of RVP on CO and NOx emissions
- RVP has no effect on evaporative emissions for vehicles fitted with an effective control system. An increase in evaporative emissions with increasing RVP was only observed for those vehicles having no, or too small a carbon canister installed.

6. "IN-TANK" FLAMMABILITY - MINIMUM RVP REQUIREMENTS

The safe distribution and use of gasoline relies on the fact that the head space in any tank is normally saturated with vapour which is above the upper flammability limit. For low RVP fuels this may not be the case. Two programmes of work have been carried out on this subject, by the US NIPER (SAE 902096) and the German DGMK (Report 462-2 1994). One critical issue is the Upper Flammability Limit (UFL) of gasoline vapour, where a range of values between 6 and 8 % v/v hydrocarbon vapour has been published. The most recent study was done by Frobese (an author of the DGMK study) who quotes a value of 7.7%. However the DGMK study itself gives the UFL as 8.5% v/v vapour, confirmed by ignitability tests. The NIPER study, while predicting from theory that UFL should be in the range 8 - 8.5 % v/v, found also by ignitability experiments that a figure of 7.1 % v/v corresponded better with their results. Other data in the literature suggests UFL for gasoline in the range 6-8%, also that unsaturated hydrocarbons have higher UFL than saturated. Thus it may be prudent to consider a relatively high value for UFL with some safety margin, say 10 %v/v.

NIPER developed a simple linear equation to predict the minimum temperature to give a non-flammable vapour/air mixture which appears to fit their data well, a version of this equation in SI units is given below:

$$T_{(ufl)}\ (^{\circ}C) = 7.778 - 0.371 * RVP\ (kPa)$$

This equation is compared with the DGMK experimental results assuming UFLs of 8.5 and 7.1 % v/v respectively in **Table 1**.

Table 6.1 Minimum temperature to form a non-flammable mixture at various RVP levels from US NIPER and German DGMK studies at different UFL levels

	Min. Temp. to form flammable mixture °C		
RVP min	NIPER (7.1)	DGMK(8.5)	DGMK(7.1)
88.0	-24.9	-20.0	-25.0
68.0	-17.5	-16.0	-20(est.)
65.0	-16.3		
60.0	-14.5		
55.0	-12.6	-7.0	-15.0
45.0	-8.9		
35.0	-5.2	-4.0	-7.0

Further calculations have been made using Raoult's law to calculate the True Vapour Pressure (TVP) equivalent to a UFL of 10 %v/v hydrocarbon vapour, and a CONCAWE equation which is derived from an earlier API nomogram, to convert TVP at a given ambient temperature to critical RVP as shown in **Table 2**.

Table 6.2 Predicted Critical RVP for various Temperatures.

Temperature	UFL	TVP crit.	Critical RVP*
Deg C	% v/v HC	kPa	kPa
0	10	10.13	32.04
-5	10	10.13	37.87
-10	10	10.13	44.74
-15	10	10.13	52.87
-20	10	10.13	62.48
-25	10	10.13	73.83

* CONCAWE Report 85/54 "Hydrocarbon emissions from gasoline storage and distribution systems", equation was developed from an earlier API correlation.

Based on the figures in **Table 6.2** and calculations using the NIPER equation, minimum RVP levels have been determined for all European countries, see **Tables 6.3** and **6.4**. The NIPER equation tends to give higher values for the critical RVP than the CONCAWE equation. Limits have been determined for both the winter period and the proposed EU directive summer period (April to September). In winter, the temperature for the coldest month has been used. For summer the lowest temperature is always in April, and figures for that month have been used. There are a number of different ways of defining minimum temperature. In this analysis minimum temperatures for individual countries have been selected, based on either the "monthly average minimum temperature" for each country, or the "monthly average minimum temperature" for the coldest location listed in each country (labelled here for convenience as the absolute minimum temperature), using data from the UK Met. Office publication Met.O.856c.

Table 6.3 shows that using the "monthly average minimum temperature" for the winter period, the current minimum RVP limits are adequate except in Nordic countries e.g. Sweden and Finland as well as in Austria, where increases in minimum RVP of 5 to 10 kPa are recommended. To prevent any danger of formation of flammable mixtures in the fuel tank head space at the *absolute* minimum temperature however, minimum RVP would have to be increased in many regions. It is likely that fuel temperatures do not reach the absolute minimum ambient temperatures which can occur at night, since the tank fuel temperature will lag behind the ambient temperature. Therefore, the "monthly average minimum temperature" provides the best basis for setting safe minimum RVP limits.

Table 6.4 shows that using the monthly average minimum temperature for the summer period including April, a minimum RVP limit of 40 kPa would give adequate protection in all countries except Scandinavia, where e.g. minimum limits of 50 kPa in Norway and 60 kPa in Finland are needed for April. This would clearly be impracticable with a maximum specification of 60 kPa as proposed in the EU draft directive.

To summarise, for winter quality gasoline, current minimum RVP limits are appropriate for all European countries except Nordic regions, e.g. Sweden and Finland as well as Austria, where increases in minimum RVP of 5-10 kPa are recommended. For summer quality, April is the critical month and some regions, principally Scandinavia, would require minimum RVP limits close to, or equal to the EU proposed 60 kPa maximum. This illustrates that a constant RVP for a fixed

6 month summer period across Europe is not appropriate given the wide temperature range.

Table 6.3 Minimum winter RVP (kPa) specifications for CEN volatility classes

CEN CLASS		**1**	**2**	**3**	**4**	**5**		**6**			**7**					**8**			
RVP min.		35	35	45	45	55		55			60					65			
RVP max.		70	70	80	80	90		90			95					100			
FVI max.		900	950	1000	1050	1100		1150			1200					1250			
Country Applic.				GR	E	I	PO	A	F	D	B	NL	DK	S	CH	SF	NO	UK	IRL
Winter Period -									1/12 -25/2										
Min. Winter Temp. (January)																			
Monthly Avg.				0	-5	-2	0	-17	-7	-12	-9	-7	-10	-22	-14	-28	-18	-5	-5
Min RVP	**CONCAWE**			**35**	**38**	**35**	**35**	**56**	**40**	**48**	**43**	**41**	**45**	**67**	**51**	**> 74**	**58**	**38**	**38**
	NIPER			**35**	**35**	**35**	**35**	**67**	**40**	**54**	**45**	**52**	**49**	**81**	**59**	**> 88**	**69**	**36**	**35**
Absolute Min				-5	-10	-20	-5	-26	-20	-23	-12	-10	-22	-30	-26	-37	-38	-13	-11
Min RVP	**CONCAWE**			**38**	**45**	**62**	**38**	**> 74**	**62**	**70**	**49**	**44**	**67**	**> 74**	**> 74**	**> 74**	**> 74**	**49**	**46**
	NIPER			**35**	**49**	**75**	**35**	**> 88**	**75**	**84**	**55**	**48**	**81**	**> 88**	**> 88**	**> 88**	**> 88**	**56**	**51**

Table 6.4 Minimum summer RVP (kPa) specifications for CEN volatility classes

1					**2**			**3**	**4**							**5**	**6**	**7**	**8**
35					35			45	45							55	55	60	65
70					70			80	80							90	90	95	100
900					950			1000	1050							1100	1150	1200	1250
F	GR	I	PO	E	A	CH	D	I,F(int)	DK	SF	B	NL	S	UK	IRL	NO			
	*)		*)	*)		*)			*)				*)		*)				
-1		5			-4		-3	-1		-15	-2	-1		-1		-10			
< 35		**< 35**			**37**		**< 35**	**< 35**		**54**	**< 35**	**< 35**		**< 35**		**45**			
< 35		**< 35**			**< 35**		**< 35**	**< 35**		**63**	**< 35**	**< 35**		**< 35**		**49**			
-15		-6			-19		-18	-15		-24	-4	-2		-6		-26			
53		**39**			**61**		**58**	**53**		**72**	**36**	**< 35**		**40**		**< 74**			
62		**37**			**73**		**69**	**62**		**87**	**< 35**	**< 35**		**38**		**< 88**			

*) temperature data were not readily available

7. CONCLUSIONS / RECOMMENDATIONS

The ad-hoc group has reviewed the proposed EU draft directive year 2000 limits for volatility specifications and believe that fixed pan-European RVP limits proposed for six months are not the most appropriate or cost effective way to achieve the desired reductions in hydrocarbon emissions.

- The specified summer period is too long
- Summer temperatures vary widely between northern and southern Europe. Fixed specifications are not appropriate.
- Vehicle cold driveability can be adversely affected in intermediate seasons
- Reducing RVP can lead to increased exhaust HC emissions during cold operation
- In-tank flammability concerns mean for the Nordic countries that minimum RVPs in April would need to be close to or above the maximum EU proposals.

Evaporative emissions and TVP (which correlates to distribution losses) depend not only on RVP but also on temperature. Effective HC emission control while avoiding the above potential problems can be achieved by applying geographically and seasonally adjusted volatility specifications. These could include the use of a shorter summer season and, in some cases, intermediate volatility grades.

8. REFERENCES

1. CONCAWE (1985) Hydrocarbon emissions from gasoline storage and distribution systems. Report No. 85/54. Brussels: CONCAWE

2. CONCAWE (1993) The effect of gasoline volatility on vehicle exhaust emissions at low ambient temperatures. Report No. 93/51. Brussels: CONCAWE

3. CONCAWE (1990) The effects of temperature and fuel volatility on vehicle evaporative emissions. Report No. 90/51. Brussels: CONCAWE

4. Naumann, M. et al (1996) The impact of gasoline vapour pressure on exhaust emissions of cars at low temperatures. Report No. 513. Hamburg: DGMK

5. API (1994) The effects of fuel RVP and fuel blends on emissions at non-FTP temperatures. API Health Environ. Sci. Dep. Rep. 4533. Washington DC: American Petroleum Institute

6. Marshall, W.F. and Schoonveld, G.A. (1990) Vapour space flammability of automobile tanks containing low RVP gasolines. SAE Paper No. 902096. Warrendale PA: Society of Automotive Engineers

7. Foerster, H. et al (1994) Investigation of the hydrocarbon concentration and the explosiveness of the atmosphere in the vapour space of vehicle tanks for petrols on the ignition limit in the vehicle tank. Report No. 462-2. Hamburg: DGMK

8. UK Met. Office (1982) Tables of temperature, relative humidity, precipitation and sunshine for the world, Part 3 - Europe and the Azores. UK Met. U.856c. London: UK Meteorological Office