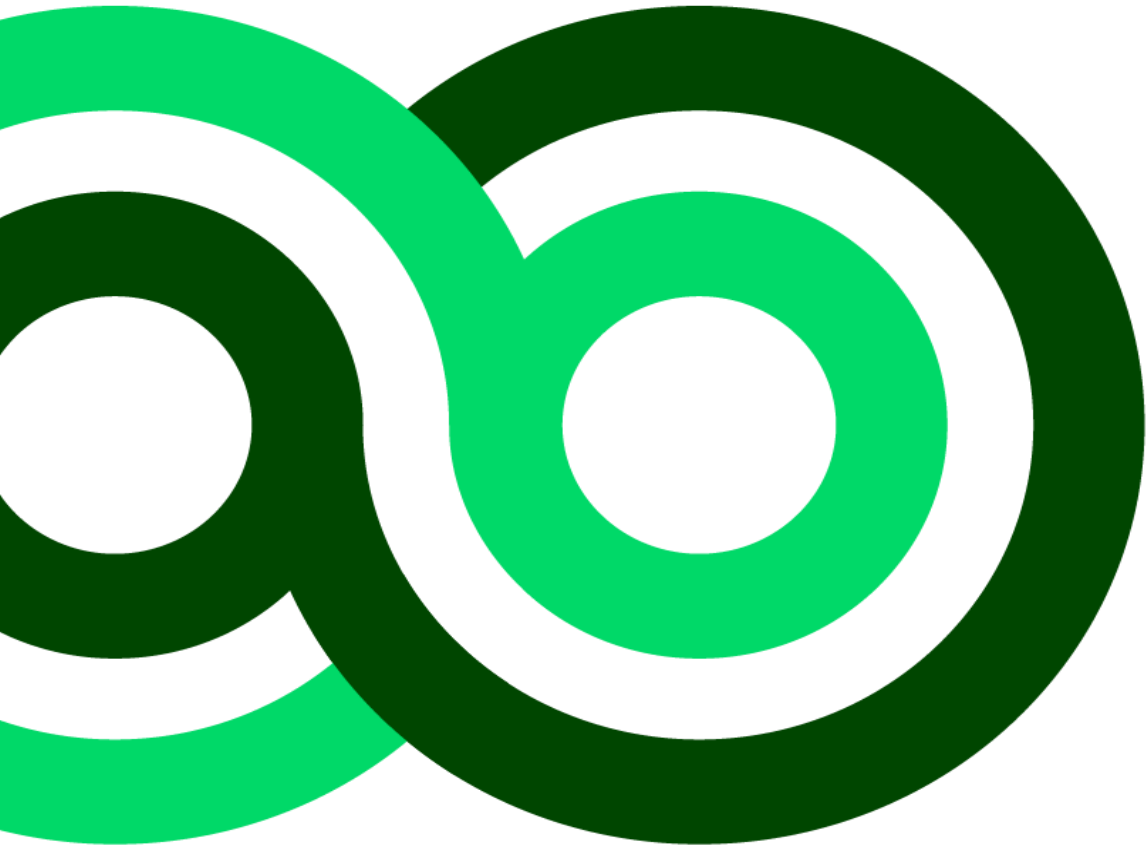
TEST PROCEDURE

Overall Rating Procedure

Version 2.0.0 February 2021



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1. INTRODUCTION

Green NCAP is an initiative established in 2018 to provide consumers with comprehensive, holistic and independent information regarding the environmental impact of new cars. Legislation in this area has become very much more rigorous, partly in response to revelations of some manufacturers 'cheating' emissions tests by utilising different software (so-called 'engine maps') when the tests are conducted to those used in normal driving. However, even without resorting to such measures, vehicle manufacturers are able, perfectly legally, to utilise those areas of the engine map which are not explored in the tests to enhance real-world performance or emissions abatement. Green NCAP conducts a wide variety of tests, based on those used in legislation but with 'extended boundaries', to explore more completely the engine speed/load range. In so doing, it aims to promote clean, efficient functioning of the engine and exhaust after-treatment at all times.

Protection of the environment is a broad topic and is divided into three areas in Green NCAP's assessments. The immediate environment, such as those in cities where people work and live, is perhaps most immediately affected by pollutant emissions: those by-products of the combustion process which are harmful to health. This is addressed by the Clean Air Index. The global environment is affected by the emission of gases which prevent heat from escaping from the planet, and which are responsible for the relentless rise in average temperatures which has been taking place for decades. This is addressed by the Greenhouse Gas Index. And, on top of this, the natural resources which need to be put into a vehicle to make it move – directly, in the form of petrol or diesel, or indirectly in the case of fossil-fuel derived electricity – are finite and should be used as sparingly as possible, for the benefit of the planet and for the consumer who pays for them. This area is addressed by the Energy Efficiency Index.

This document details the way in which the results of Green NCAP's tests are scored and how those scores are used to calculate the star rating.

2. THE STAR RATING

The star rating is derived from the three indexes: Clean Air, Energy Efficiency and Greenhouse Gas. The methods used to calculate those indexes will be described in the sections to follow. For now, it is sufficient to know that index is a score, out of a maximum of ten, for the performance of the vehicle in each of those three areas of assessment. Ten points represents the maximum points that are available in each of the pillars.

2.1. Weighted average

The three indexes, each to one decimal place, are used to calculate a weighted average, known as the 'overall index'. Currently the weighting is as follows:

Table 1 Index Weightings

Index	Clean Air	Energy Efficiency	Greenhouse Gas
Weight	0.333	0.333	0.333

In other words, all three indexes are given equal weighting and the overall index is, for now, a simple average of the three. The weighted average is rounded *down* to the nearest one decimal place e.g. indexes for Clean Air, Energy Efficiency and Greenhouse Gases of 4.9, 5.1 and 4.9 respectively yields a weighted average of 4.967. This is rounded to 4.9, *not* to 5.0, as the threshold of 4.9 has been met and exceeded, while the threshold of 5.0 has not.

The overall index is then compared to a table of thresholds, at which the car is deemed to have met the requirements of certain star, or half-star, ratings. The table is:

Table 2 Star Rating Thresholds

Stars	Threshold
★★★★★	9.0
★★★★½	8.0
★★★★☆	7.0
★★★½☆	6.0
★★★☆☆	5.0
★★½☆☆	4.0
★★☆☆☆	3.0
★½☆☆☆	2.0
★☆☆☆☆	1.0
☆☆☆☆☆	0.0

So a car with an overall index of 5.2 is rated as a three-star vehicle; another with an overall index of 2.8 is considered a one-and-a-half-star vehicle.

2.2. Applicability of the rating system

Ratings are independent from vehicle class. The system is prepared to deal with a variety of propulsion technologies: vehicles with an internal combustion engine (petrol, diesel, CNG), battery electric (BEV), hybrid and hydrogen vehicles. As of January 2021, plug-in hybrid vehicles (PHEV) are included.

Bi-fuel vehicles, e.g.. CNG / petrol are tested in CNG mode, but undergo in addition a limited amount of additional tests in petrol mode (WLTC-warm, PEMS+ and BAB Motorway). When for a specific constituent the ratio between primary and secondary fuel exceeds 1.5, a modifier of 50% is applied.

For monovalent CNG vehicles, where petrol serves only a fall back mode the modifier is 10%. If the emitted amount of a component in secondary fuel mode is doubled, but still is below the limit, no modifier shall be applied.

PHEV's are tested in charge sustaining (CS) mode with a limited number of additional tests in charge depleting (CD) mode[1]: WLTC cold, PEMS cold engine, PEMS light, PEMS heavy and PEMS 8km. All constituents and energy use figures are measured in both CS and CD mode as none of the modes is the exclusive domain of either ICE or electric propulsion technology.
For each area of assessment, scores from the tests performed in CD and CS mode are used to calculate a 'sub-index' for each mode. These are then combined using a weighted average depending on the driving range in charge depleting mode. The bigger the range in charge depleting mode, the smaller the influence of the results in sustaining mode and the other way round, see table 3. The driving range in charge depleting mode is calculated as the equivalent all-electric range (EAER) as defined in legislation.

Table 1: CS/CD ratio determining ratings

PHEV	Depleting Mode	Sustaining Mode
If range is ≥ 100 km	80%	20%
If 25 km ≤ range ≤ 100 km	Sliding Scale	
If range is ≤ 25 km	20%	80%

[1] operation dependent on the energy from the battery pack

3. THE INDEXES

3.1. The Clean Air Index

3.2. The Pollutants

The pollutants considered in the calculation of the Clean Air Index are as follows:

Table 3 Pollutant Emissions

Pollutant	Abbreviation
Non-methane hydrocarbons	NMHC
Oxides of nitrogen	NO_x
Nitrogen dioxide	NO_2
Ammonia	NH_3
Carbon Monoxide	CO
Particulate Mass	PM
Particulate Number	PN

1.1.1. The Tests

The tests employed are as follows:

Table 4 Green NCAP Tests

	Test
Laboratory Tests	WLTC – cold start (WLTC-cold) (14˚C)
	WLTC – warm start (WLTC – warm)
	WLTC – cold ambient temp (WLTC-CAT) (-7˚C)
	Motorway test (BAB130)
Real Driving Emissions	PEMS (cold Engine, 2 times)
	PEMS (Short urban trip, 2 times)
	PEMS (Eco/light)
	PEMS (Heavy load)
	PEMS (Congestion)

WLTC: World-harmonised Light-duty Test Cycle
PEMS: Portable Emissions Measuring System
The procedures used for each of the tests is described in detail in other Green NCAP procedures

1.1.2. Limit Values

For each test, the scoring of each relevant pollutant is based on the final bag measurement of that pollutant. For each, there is a lower emissions (i.e. high-performance) limit, below which maximum points are scored, and an upper emissions (i.e. low-performance) limit above which no, or negative, points are scored. There is also a 'gross exceedence' limit for each pollutant (1.5 times upper limit, except PN: one order of magnitude. Different limit values apply to different tests, as follows:

Table 5 Clean Air Limit Values (1): Applies to: WLTC-cold, WLTC-warm, BAB130

Pollutant	Lower Limit	Upper Limit	Gross Exceedence
NMHC (mg/km)	0.0	58	87
NO_x (mg/km)	0.0	60	90
NO_2 (mg/km)	0.0	20	30
NH_3 (mg/km)	0.0	10	15
CO (mg/km)	0.0	500	750
PM (mg/km)	0.0	4.5	6.75
PN	0.0	6×10^{11}	6×10^{12}

Table 6 Clean Air Limit Values (2): Applies to: PEMS+ cold, PEMS light load, PEMS congestion, WLTC-CAT, PEMS heavy load, PEMS 8km

(a conformity factor of 1.32 is applied for PEMS compared to laboratory tests)

Pollutant	Lower Limit	Upper Limit	Gross Exceedence
NMHC (mg/km) [1]	not tested		
NO_x (mg/km)	0.0	79	119
NO_2 (mg/km) [1]	0.0	26	40
NH_3 (mg/km) [1]	0.0	13	20
CO (mg/km)	0.0	660	990
PM (mg/km)[1]	0.0	6	9
PN	0.0	7.92×10^{11}	1.0×10^{12}

[1] Not relevant to PEMS tests

For the PEMS congestion test, only NO_x is measured and the limits are as follows:

Table 7 Clean Air Limit Values (3)

Pollutant	Average	Maximum
NO_x (mg/s)	0.5	1.0

3.2.1. The Scoring Principle

Within each test, each pollutant can score a maximum number of points for values of emissions which are at or below the lower limit, down to zero at the upper limit, and can be negative for values beyond the upper limit. Particulate number is calculated on a logarithmic scale while all other pollutants are scored linearly.

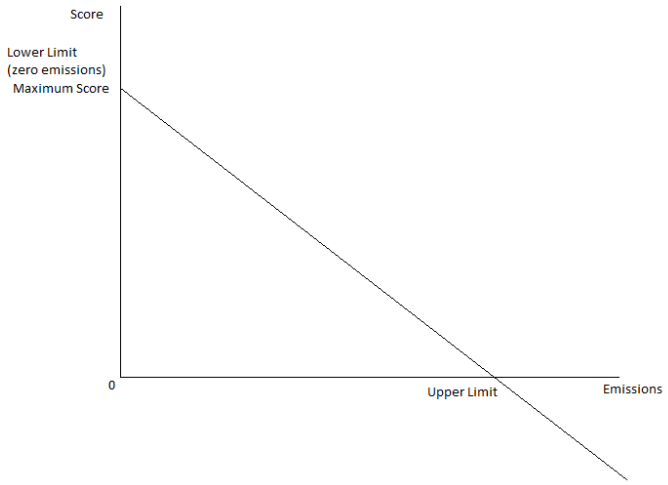

Figure 1 Linear Scoring Method

For particulate number, a logarithmic scale is used

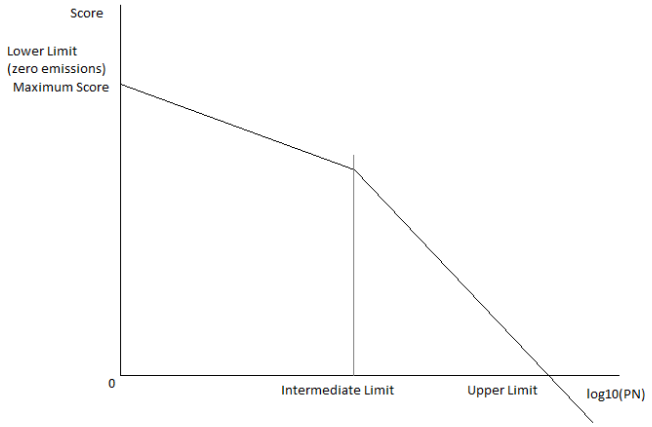

Figure 2 Logarithmic Scoring for Particulate Number

The maximum score per pollutant varies by test.

Table 8 Maximum Scores per Test (Clean Air)

Pollutant	all WLTC and BAB130	PEMS+ cold	PEMS light	PEMS heavy	PEMS 8km [2]	PEMS congestion
NMHC (mg/km)	2	-	-	-	-	-
NO_x (mg/km[1])	3	2	2.25	3.6	1.125	2
NO_2 (mg/km)	0	-	-	-	-	-
NH_3 (mg/km)	1	-	-	-	-	-
CO (mg/km)	1	1	0.5	0.8	0.25	-
PM (mg/km)	0	-	-	-	-	-
PN	3	2	2.25	3.6	1.125	-
Maximum Points	**10**	**5**	**5**	**8**	**2.5**	**2**

[1] mg/s for the PEMS Congestion test

[2] carried out twice

The total score per test is the sum of the scores for the individual pollutants, with the following notes:

- Capping. If any pollutant, with the exception of NH_3, exceeds its gross exceedence value, the score for that test is set to zero, regardless of the performance of the other pollutants. Tests are not capped in this way for NH_3 which is unregulated by legislation.
- If the sum of the scores of individual pollutants is less than zero, the score for the test is set to zero i.e. the minimum score for tests in the Clean Air Index is zero.
- In the PEMS Congestion test, a score of 1 point is awarded if the average NO_x emission rate is less than the prescribed maximum, and an additional 1 point is awarded if the maximum NO_x emission rate is lower than its prescribed maximum.
- Scoring for PEMS light: if the value of any pollutant is less than its value in the PEMS+ cold test, the maximum score is awarded for that pollutant. If the value of the pollutant is above the upper limit, no points are scored. For values between that in the PEMS+ cold test and the upper limit, a sliding scale is used.
- Scoring for PEMS heavy: if the score for that pollutant in the PEMS+ cold test was zero, then no points can be scored for that pollutant in the PEMS heavy test. Otherwise, if the value of the pollutant emissions is less than the upper limit of the PEMS+ cold test, maximum points are scored for that pollutant.
- Scoring for PEMS 8km: the test is done twice. For both tests, the following applies: if the score for a pollutant was zero in the PEMS+ cold test, then no points can be scored for that pollutant in the PEMS heavy test. If the value of the pollutant emissions in *either* of the PEMS 8km tests

exceeds the (extended) gross exceedence limit, then the score for that pollutant is zero. Otherwise, the score is calculated on a sliding scale between (maximum points at zero to zero points at the gross exceedence limit.

3.2.2. Total Score and Calculation of the Index

The points from each of the tests are summed and the result is divided by the maximum points that can be achieved in the Clean Air assessment (currently 40). The result is rounded down to one decimal place and multiplied by ten.

3.3. The Greenhouse Gas Index

3.3.1. The Greenhouse Gases

The gases considered in the calculation of the Greenhouse Gas Index are as follows:

Table 9 Greenhouse Gases

Greenhouse Gas		Abbreviation
Carbon dioxide		CO_2
Nitrous oxide		N_2O
Methane		CH_4

3.3.2. The Tests

The tests used are the same as those used for the Clean Air Index. See Section 3.2.1

3.3.3. Limit Values

The following limit values apply:

Table 10 Greenhouse Gas Limit Values (1): Applies to: WLTC-cold, WLTC-warm, BAB130

Pollutant	Lower Limit	Upper Limit
CO_2 (g/km)	0.0	175
N_2O (mg/km)	0.0	6.2
CH_4 (mg/km)	0.0	32

Table 11 Greenhouse Gas Limit Values (2): Applies to: PEMS+ cold, PEMS light load, PEMS congestion, WLTC-CAT, PEMS heavy load, PEMS 8km

(a conformity factor of 1.5 is applied for PEMS compared to laboratory tests)

Pollutant	Lower Limit	Upper Limit
CO_2 (g/km)	0.0	262.5
N_2O (mg/km)	0.0	9.3
CH_4 (mg/km)	0.0	48

Table 12 Greenhouse Gas Limit Values (3): Applies to: WLTC-CAT

(a conformity factor of 1.6 is applied for WLTC-CAT to other laboratory tests)

Pollutant	Lower Limit	Upper Limit
CO_2 (g/km)	0.0	175
N_2O (mg/km)	0.0	9.92
CH_4 (mg/km)	0.0	51.2

3.3.4. The Scoring Principle

Points are scored in the same way as for pollutants in the Clean Air Index. Only a linear scale is used in this case. The maximum score per gas varies by test.

Table 13 Greenhouse Gas Maximum Scores per Test

Greenhouse Gas	all WLTC and BAB130	All PEMS tests[1]
CO_2	1	0
N_2O	2	0
CH_4	4	0
Maximum Points	**7**	**0**

[1] Greenhouse gases measured in PEMS tests are not currently used for scoring

3.3.5. Total Score and Calculation of the Index

The points from each of the tests are summed and the result is divided by the maximum points that can be achieved in the Greenhouse Gas assessment (currently 28) and multiplied by ten. The result is rounded down to one decimal place.

3.4. The Energy Efficiency Index

3.4.1. What is measured?

In simple terms, energy consumption is measured. The precise way in which this is done varies by fuel/energy type and details are contained in the individual test procedures. In summary, units of consumption are as follows:

Table 14 Energy Efficiency Units of Consumption

Energy Source	Units of Consumption
Petrol, Diesel	l / 100km
Battery Electric	kWh / 100km
CNG, Hydrogen Fuel Cell	kg / 100km

3.4.2. The Tests

Energy Efficiency is calculated on the basis of results in the laboratory tests defined previously. (PEMS test are not suitable). See Section 1.1.1.

3.4.3. Energy Equivalent

To be able to compare energy efficiency between the different power sources, the consumption is converted into an equivalent energy. Conversion factors are based on the known calorific content of the fuel types. In the case of battery electric vehicles, no conversion is needed as the units of consumption are already in SI units.

Table 15 Energy Conversion Factors

Energy Source	Conversion Factor to kWh / 100km
Petrol (RON95, E10)	8.64
Diesel B7	9.79
CNG (high Methane)	13.89
Hydrogen	33.61
Electricity	1.00

3.4.4. The Scoring Principle

A linear sliding scale is used for scoring, as described in Section 3.2.1.
The following limits and scores are used for all tests and for all engine types/energy sources:

Table 15 Energy Efficiency Limits

Lower Limit kWh / 100km	Upper Limit kWh / 100km	Maximum Score (≤ Lower Limit)	Score at Upper Limit
30	90	10	0

Notes:

- Energy consumption beyond the upper limit leads to negative scores. The minimum score per test is limited to zero.

3.4.5. Calculation of the Energy Efficiency Index

The scores for the four lab tests are summed (taking into account that the score for any individual test may be negative). The total is divided by the maximum points available in this part of the assessment (currently 40) and multiplied by ten. The result is rounded down to one decimal place.

3.5. VISUALISATION OF RESULTS

Green NCAP's website presents the results of the tests to consumers in a way that is easy to comprehend. A colour scheme is adopted, representing different levels of performance. The logic for choosing the colour is based on the score as a proportion of the maximum that could have been scored. This applies to the individual pollutants and gases in each test, to the energy efficiency in each test, and also to indicators of overall performance, such as all laboratory tests combined for example.
The colouring logic is as follows:

Table 16 Logic for Colouring in Visualisation

Colour	Description	Logic (x = Score/Max Score)
Green	Good	x >=0.90
Yellow	Adequate	0.60 <= x < 0.90
Orange	Marginal	0.30 <= x < 0.60
Brown	Weak	0.00 < x < 0.30
Red	Poor	x <= 0.00

4. APPENDIX 1

Rationale behind method and limit values

Section	Rationale
2.1	Currently, the average index takes equal weights from Clean Air, Energy Efficiency and Greenhouse Gases. This makes all three equally important in terms of their influence on the star rating, reflecting equal weighting for public health, consumer spending and global warming, respectively. In Greenhouse Gases, CO_2 is one of the main constituents upon which the index is scored. In Energy Efficiency, CO_2 is used as a proxy for fuel consumption for combustion-engined cars. This weighting will be reviewed in the future. Bi-fuel vehicles, e.g. CNG/petrol, are also undergo a limited amount of additional tests in petrol mode (WLTC-warm, PEMS+ and BAB Motorway). When for a specific component the ratio between primary and secondary fuel exceeds 1.5 a modifier of 50% is applied. If the emitted amount of a component in secondary fuel mode is doubled, but still below the limit, no modifier shall be applied. [PHEV's are tested in charge depletion as well as charge sustaining mode. Results will be combined]
3.2	These are the pollutant emissions which are considered the most important ones which can be measured. Particle number (PN) is based on measurement of PN23 particles. Research has been done to study the correlation between this number and the number of sub-10nm (PN10) particles. The measurement method may be refined to PN10 in time.
1.1.1	Details of the test methods are given in other procedures. Laboratory tests (WLTC and BAB130) are based on established test procedures. However, Green NCAP extends the boundary conditions to include different start temperatures and different ambient temperatures. In the same vein, the on-road tests are performed in a variety of load conditions – light load, heavy load etc – to better simulate real-world car use.
1.1.2	The same limit values are used for all fuel and types and energy sources, to makes the assessment and comparison of results technology-neutral. The lower limit values are always set to zero emissions. In other words, only zero tailpipe emissions are given maximum score for the Clean Air Index. The upper limits for laboratory tests are based on the lowest value of diesel and petrol Euro 6d limit values. As this is the allowable legal limit, no points are scored for the pollutant at these values or beyond. In the THC limit CH4 was taken out and shifted to 'Greenhouse Gas', resulting in a limit NMHC. The gross exceedence limit represents the point at which the score for the entire test is capped to zero i.e. if any constituent pollutant reaches or exceeds this value, no points are scored in that test. The only exception is ammonia, NH_3, which is not regulated by legislation. For NH3 the limit value is derived from the requirements for HDVs (UN-R49) A conformity factor of 1.32 (recommended by JRC) is applied for the upper limits of PEMS tests compared to the lab tests as measurement repeatability is less precise.
3.2.1	A linear scale is used for scoring of all pollutants except PN, between a maximum number of points for zero emissions, to zero points at the upper limit. Beyond this limit, scoring becomes negative, following the same slope. This, a car which performs well for one pollutant will have its score in that test decreased if another pollutant is above the upper limit. This encourages good performance all-round and discourages optimisation of one at the expense of another pollutant. For PN, a logarithmic scale is used, decreasing from a maximum at zero to 2/3 x Maximum at a value of 10^8 (i.e. a $\log_{10}$ value of 8) and, from there, to a score of zero at 6×10^{11}, the Euro 6d limit. Beyond 6×10^{11}, the score continues to follow the line, becoming negative.

	The maximum score per pollutant reflects their relative harmful effects, and varies by the importance of the test.
3.3.1	These are the three most significant greenhouse gases emitted by vehicles. CO_2 is emitted in vastly greater quantities than N_2O or CH_4. However, the latter have a more powerful greenhouse gas effect, and last longer in the atmosphere.
3.3.3	CH_4 and N_2O are not regulated in Europe. The upper limit value for N2O is taken from US legislation. CH_4 upper threshold corresponds to the subtraction of THC_Euro6 by the NMHC_Euro6 limits The CO_2 limit is derived from the fleet average of cars tested in ADACs Ecotest program. There are no gross exceedance values for the Greenhouse Gas Index, and no capping of tests.
3.3.4	The maximum scores reflect the relative importance of the greenhouse gases. Only a linear scale is used in this index. Measurements in PEMS tests are not yet repeatable enough to be used in the calculation of this index, so their maximum scores are zero (i.e. they do not currently contribute to the Greenhouse Gas Index)
3.4.3	Standard test fuels are used, with known calorific properties.
3.4.4	A linear scale is used. However, for energy efficiency, the lower limit (maximum points) is not zero, as all cars need to use *some* energy to move. The lower limit in this case is 30 kWh/100km; the upper limit, at which no points are scored, is 90 kWh/100km. These values are chosen to reflect the typical range of energy consumptions seen in modern vehicles and to give some resolution in results. The minimum score per test is zero (i.e. a test cannot have a negative score).
3.5	Colours are based on scores as a proportion of the maximum available for that constituent in that test. With lower limits of zero (i.e. any tailpipe emission leads to a drop in score), a band of 10 percent is allowed to define ‘good’ performance. ‘Poor’ performance is defined as a value of emission at or beyond the prescribed upper limit. The bands representing other levels of performance are split equally between in the range 0 = 90 percent.