Council of the
European Union

Brussels, 12 December 2016
(OR. en)

15472/16
ADD 3

ENT 230
ENV 794
MI 792

COVER NOTE

From:	European Commission
date of receipt:	9 December 2016
To:	General Secretariat of the Council
No. Cion doc.:	D045884/02 ANNEX 3 - PART 2/3
Subject:	ANNEX to the Commission Regulation supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information, amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) No 1230/2012 and repealing Regulation (EC) No 692/2008

Delegations will find attached document D045884/02 ANNEX 3 - PART 2/3.

Encl.: D045884/02 ANNEX 3 - PART 2/3

EUROPEAN
COMMISSION

Brussels, XXX
D045884/02
[…](2016) XXX draft

ANNEX 3 – PART 2/3

ANNEX

to the

Commission Regulation

supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information, amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) No 1230/2012 and repealing Regulation (EC) No 692/2008

Appendix 5

Verification of trip dynamic conditions and calculation of the final RDE emissions result with method 1 (Moving Averaging Window)

1. INTRODUCTION

The Moving Averaging Window method provides an insight on the real-driving emissions (RDE) occurring during the test at a given scale. The test is divided in sub-sections (windows) and the subsequent statistical treatment aims at identifying which windows are suitable to assess the vehicle RDE performance.

The “normality” of the windows is conducted by comparing their CO_2 distance-specific emissions[1] with a reference curve. The test is complete when the test includes a sufficient number of normal windows, covering different speed areas (urban, rural, motorway).

Step 1. Segmentation of the data and exclusion of cold start emissions (section 4 in Appendix 4);

Step 2. Calculation of emissions by sub-sets or “windows” (section 3.1);

Step 3. Identification of normal windows (section 4);

Step 4. Verification of trip completeness and normality (section 5);

Step 5. Calculation of emissions using the normal windows (section 6).

2. SYMBOLS, PARAMETERS AND UNITS

Index (i) refers to the time step

Index (j) refers to the window

Index (k) refers to the category (t=total, u=urban, r=rural, m=motorway) or to the CO_2 characteristic curve (cc)

Index “gas” refers to the regulated exhaust gas components (e.g. NO_x, CO, PN)

Δ	-	difference
≥	-	larger or equal
#	-	number
%	-	per cent

[1] For hybrids, the total energy consumption shall be converted to CO_2. The rules for this conversion will be introduced in a second step.

$\leq$	-	smaller or equal
a_1, b_1	-	coefficients of the CO_2 characteristic curve
a_2, b_2	-	coefficients of the CO_2 characteristic curve
d_j	-	distance covered by window *j* [km]
f_k	-	weighting factors for urban, rural and motorway shares
h	-	distance of windows to the CO_2 characteristic curve [%]
h_j	-	distance of window j to the CO_2 characteristic curve [%]
$\bar{h}_k$	-	severity index for urban, rural and motorway shares and the complete trip
k_{11}, k_{12}	-	coefficients of the weighting function
k_{21}, k_{21}	-	coefficients of the weighting function
$M_{CO2,ref}$	-	reference CO_2 mass [g]
M_{gas}	-	mass or particle number of the exhaust component “gas” [g] or [#]
$M_{gas,j}$	-	mass or particle number of the exhaust component “gas” in window j [g] or [#]
$M_{gas,d}$	-	distance-specific emission for the exhaust component “gas” [g/km] or [#/km]
$M_{gas,d,j}$	-	distance-specific emission for the exhaust component “gas” in window j [g/km] or [#/km]
N_k	-	number of windows for urban, rural, and motorway shares
P_1, P_2, P_3	-	reference points
t	-	time [s]
$t_{1,j}$	-	first second of the j^{th} averaging window [s]
$t_{2,j}$	-	last second of the j^{th} averaging window [s]
t_i	-	total time in step i [s]
$t_{i,j}$	-	total time in step *i* considering window *j* [s]
tol_1	-	primary tolerance for the vehicle CO_2 characteristic curve [%]
tol_2	-	secondary tolerance for the vehicle CO_2 characteristic curve [%]
t_t	-	duration of a test [s]
v	-	vehicle speed [km/h]
$\bar{v}$	-	average speed of windows [km/h]

v_i - actual vehicle speed in time step i [km/h]

$\bar{v}_j$ - average vehicle speed in window j [km/h]

$\overline{v_{P1}} = 19\ km/h$ - average speed of the Low Speed phase of the WLTP cycle

$\overline{v_{P2}} = 56.6\ km/h$ - average speed of the High Speed phase of the WLTP cycle

$\overline{v_{P3}} = 92.3\ km/h$ - average speed of the Extra High Speed phase of the WLTP cycle

w - weighting factor for windows

w_j - weighting factor of window j

3. MOVING AVERAGING WINDOWS

3.1. Definition of averaging windows

The instantaneous emissions calculated according to Appendix 4 shall be integrated using a moving averaging window method, based on the reference CO_2 mass. The principle of the calculation is as follows: The mass emissions are not calculated for the complete data set, but for sub-sets of the complete data set, the length of these sub-sets being determined so as to match the CO_2 mass emitted by the vehicle over the reference laboratory cycle. The moving average calculations are conducted with a time increment Δt corresponding to the data sampling frequency. These sub-sets used to average the emissions data are referred to as "averaging windows". The calculation described in the present point may be run from the last point (backwards) or from the first point (forward).

The following data shall not be considered for the calculation of the CO_2 mass, the emissions and the distance of the averaging windows:

– The periodic verification of the instruments and/or after the zero drift verifications;

– The cold start emissions, defined according to Appendix 4, point 4.4;

– Vehicle ground speed < 1 km/h;

– Any section of the test during which the combustion engine is switched off.

The mass (or particle number) emissions $M_{gas,j}$ shall be determined by integrating the instantaneous emissions in g/s (or #/s for PN) calculated as specified in Appendix 4.

Figure 1

Vehicle speed versus time - Vehicle averaged emissions versus time, starting from the first averaging window

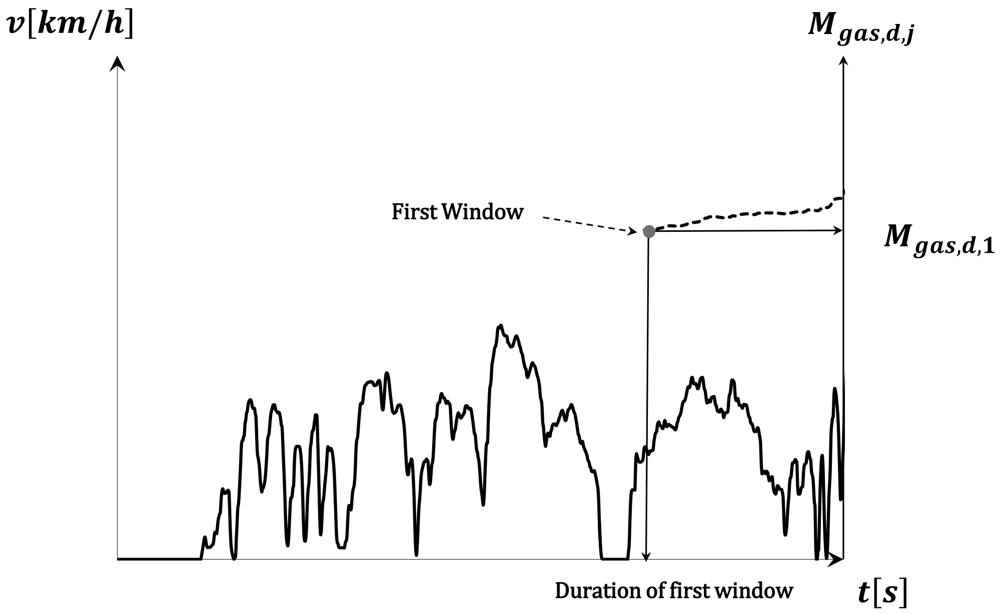
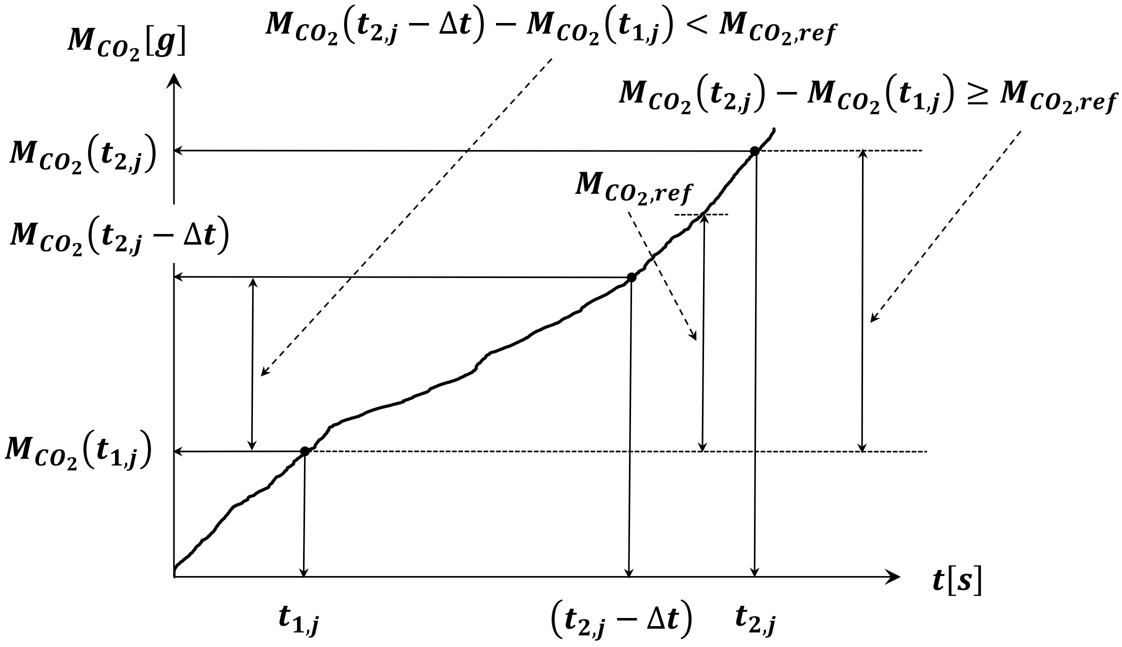


Figure 2

Definition of CO_2 mass based on averaging windows



The duration $(t_{2,j} - t_{1,j})$ of the j[th] averaging window is determined by:

$$M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j}) \geq M_{CO_2,ref}$$

where:

$M_{CO_2}(t_{i,j})$ is the CO_2 mass measured between the test start and time $(t_{2,j})$ [g];

$M_{CO_2,ref}$ is the half of the CO_2 mass [g] emitted by the vehicle over the Worldwide harmonized Light vehicles Test Cycle (WLTC) described in the UNECE Global Technical Regulation No. 15 - Worldwide harmonized Light vehicles Test Procedure (ECE/TRANS/180/Add.15; Type I test, including cold start);

$t_{2,j}$ shall be selected such as:

$$M_{CO_2}(t_{2,j} - \Delta t) - M_{CO_2}(t_{1,j}) < M_{CO_2,ref} \leq M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j})$$

where Δt is the data sampling period.

The CO_2 masses are calculated in the windows by integrating the instantaneous emissions calculated as specified in Appendix 4 to this Annex.

3.2. Calculation of window emissions and averages

The following shall be calculated for each window determined in accordance with point 3.1.,

- The distance-specific emissions $M_{gas,d,j}$ for all the pollutants specified in this annex;

- The distance-specific CO_2 emissions $M_{CO2,d,j}$;

- The average vehicle speed $\bar{v}_j$

4. EVALUATION OF WINDOWS

4.1. Introduction

The reference dynamic conditions of the test vehicle are set out from the vehicle CO_2 emissions versus average speed measured at type approval and referred to as “vehicle CO_2 characteristic curve”.

To obtain the distance-specific CO_2 emissions, the vehicle shall be tested on the chassis dynamometer by applying the vehicle road load settings as determined following the procedure prescribed in Annex 4 of the UNECE Global Technical Regulation No. 15 - Worldwide harmonized Light vehicles Test Procedure (ECE/TRANS/180/Add.15). The road loads shall not account for the mass added to the vehicle during the RDE test, e.g. the co-pilot and the PEMS equipment.

4.2. CO_2 characteristic curve reference points

The reference points P_1, P_2 and P_3 required to define the curve shall be established as follows:

4.2.1. Point P_1

$\overline{v_{P1}} = 19\ km/h$ (average speed of the Low Speed phase of the WLTP cycle)

M_{CO_2,d,P_1} = Vehicle CO_2 emissions over the Low Speed phase of the WLTP cycle x 1.2 [g/km]

4.2.2. Point P_2

4.2.3. $\overline{v_{P2}} = 56.6\ km/h$ *(average speed of the High Speed phase of the WLTP cycle)*

M_{CO_2,d,P_2} = Vehicle CO_2 emissions over the High Speed phase of the WLTP cycle x 1.1 [g/km]

4.2.4. Point P_3

4.2.5. $\overline{v_{P3}} = 92.3\ km/h$ *(average speed of the Extra High Speed phase of the WLTP cycle)*

M_{CO_2,d,P_3} = Vehicle CO_2 emissions over the Extra High Speed phase of the WLTP cycle x 1.05 [g/km]

4.3. CO_2 characteristic curve definition

Using the reference points defined in section 4.2, the characteristic curve CO_2 emissions are calculated as a function of the average speed using two linear sections (P_1, P_2) and (P_2, P_3). The section (P_2, P_3) is limited to 145 km/h on the vehicle speed axis. The characteristic curve is defined by equations as follows:

For the section (P_1, P_2):

$$M_{CO_2,d,CC}(\bar{v}) = a_1\bar{v} + b_1$$

$$with: a_1 = \left(M_{CO_2,d,P_2} - M_{CO_2,d,P_1}\right)/(\overline{v_{P2}} - \overline{v_{P1}})$$
$$and: b_1 = M_{CO_2,d,P_1} - a_1\overline{v_{P1}}$$

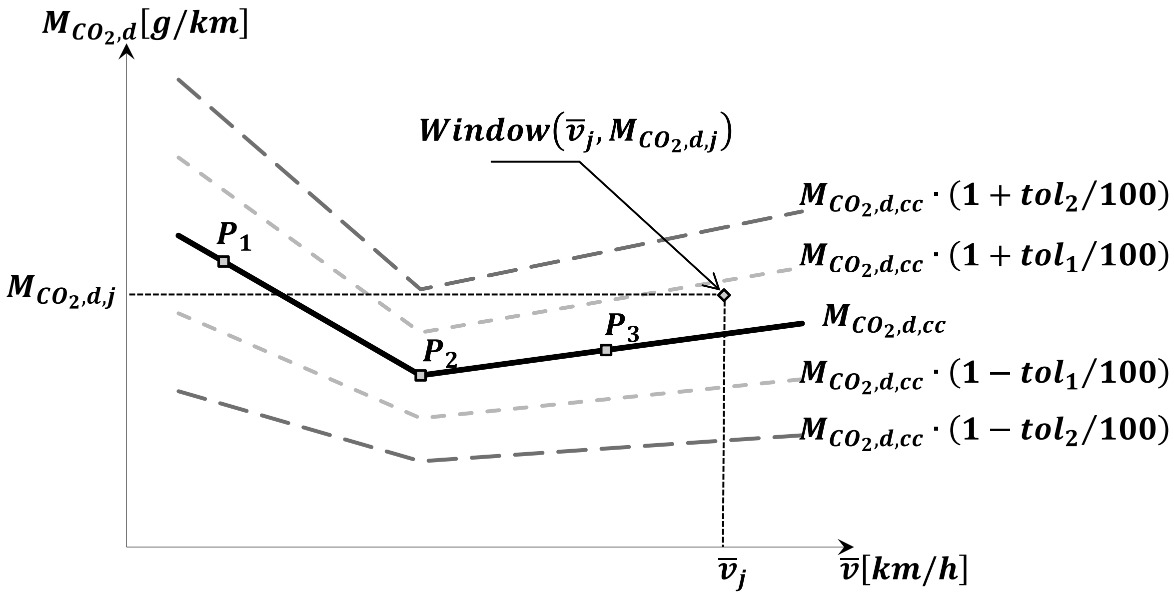
For the section (P_2, P_3):

$$M_{CO_2,d,CC}(\bar{v}) = a_2\bar{v} + b_2$$

$$with: a_2 = \left(M_{CO_2,d,P_3} - M_{CO_2,d,P_2}\right)/(\overline{v_{P3}} - \overline{v_{P2}})$$
$$and: b_2 = M_{CO_2,d,P_2} - a_2\overline{v_{P2}}$$

Figure 3

Vehicle CO_2 characteristic curve



4.4. Urban, rural and motorway windows

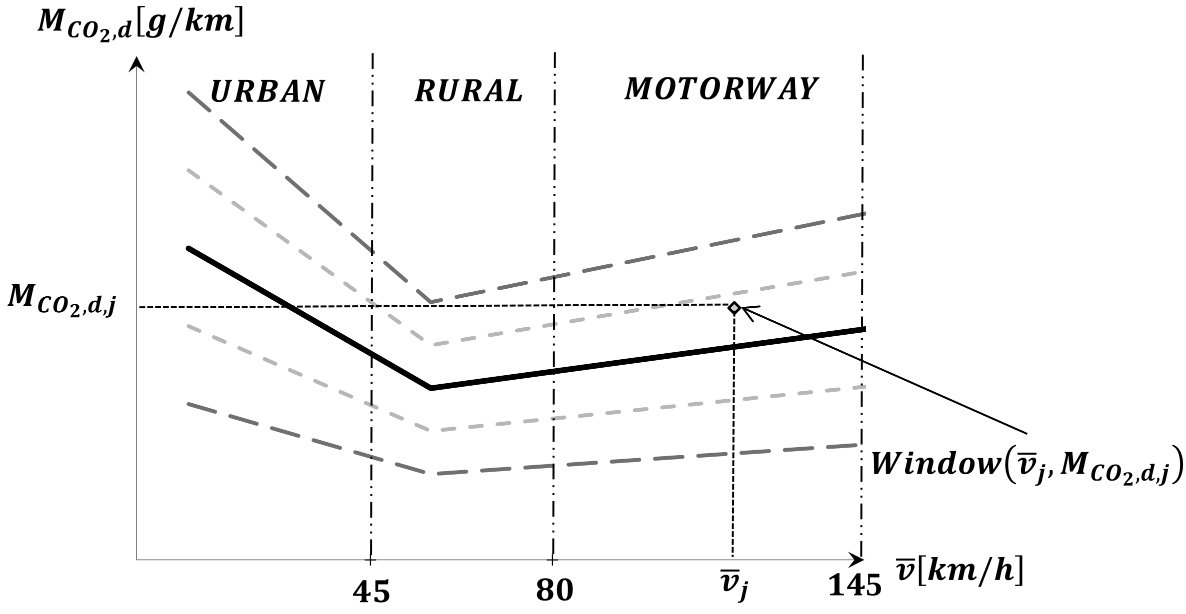
4.4.1. Urban windows are characterized by average vehicle ground speeds $\bar{v}_j$ smaller than 45 km/h,

4.4.2. Rural windows are characterized by average vehicle ground speeds $\bar{v}_j$ greater than or equal to 45 km/h and smaller than 80 km/h,

4.4.3. Motorway windows are characterized by average vehicle ground speeds $\bar{v}_j$ greater than or equal to 80 km/h and smaller than 145 km/h

Figure 4

Vehicle CO_2 characteristic curve: urban, rural and motorway driving definitions



5. VERIFICATION OF TRIP COMPLETENESS AND NORMALITY

5.1. Tolerances around the vehicle CO_2 characteristic curve

The primary tolerance and the secondary tolerance of the vehicle CO_2 characteristic curve are respectively $tol_1 = 25\%$ and $tol_2 = 50\ \%$.

5.2. Verification of test completeness

The test shall be complete when it comprises at least 15% of urban, rural and motorway windows, out of the total number of windows.

5.3. Verification of test normality

The test shall be normal when at least 50% of the urban, rural and motorway windows are within the primary tolerance defined for the characteristic curve.

If the specified minimum requirement of 50% is not met, the upper positive tolerance tol_1 may be increased by steps of 1 percentage point until the 50% of normal windows target is reached. When using this approach, tol_1 shall never exceed 30%.

6. CALCULATION OF EMISSIONS

6.1. Calculation of weighted distance-specific emissions

The emissions shall be calculated as a weighted average of the windows' distance-specific emissions separately for the urban, rural and motorway categories and the complete trip.

$$M_{gas,d,k} = \frac{\sum(w_j M_{gas,d,j})}{\sum w_j} \quad k = u, r, m$$

The weighting factor w_j for each window shall be determined as such:

If $M_{CO2,d,CC}(\bar{v}_j).(1 - tol_1/100) \leq M_{CO2,d,j} \leq M_{CO2,d,CC}(\bar{v}_j).(1 + tol_1/100)$

Then $w_j = 1$

If

$$M_{CO2,d,CC}(\bar{v}_j).(1 + tol_1/100) < M_{CO2,d,j} \leq M_{CO2,d,CC}(\bar{v}_j).(1 + tol_2/100)$$

Then $w_j = k_{11}h_j + k_{12}$

With $k_{11} = 1/(tol_1 - tol_2)$

and $k_{12} = tol_2/(tol_2 - tol_1)$

If

$$M_{CO2,d,CC}(\bar{v}_j).(1 - tol_2/100) \leq M_{CO2,d,j} < M_{CO2,d,CC}(\bar{v}_j).(1 - tol_1/100)$$

Then $w_j = k_{21}h_j + k_{22}$

with $k_{21} = 1/(tol_2 - tol_1)$

and $k_{22} = k_{12} = tol_2/(tol_2 - tol_1)$

If

$$M_{CO2,d,j} < M_{CO2,d,CC}(\bar{v}_j).(1 - tol_2/100)$$

or

$$M_{CO2,d,j} > M_{CO2,d,CC}(\bar{v}_j).(1 + tol_2/100)$$

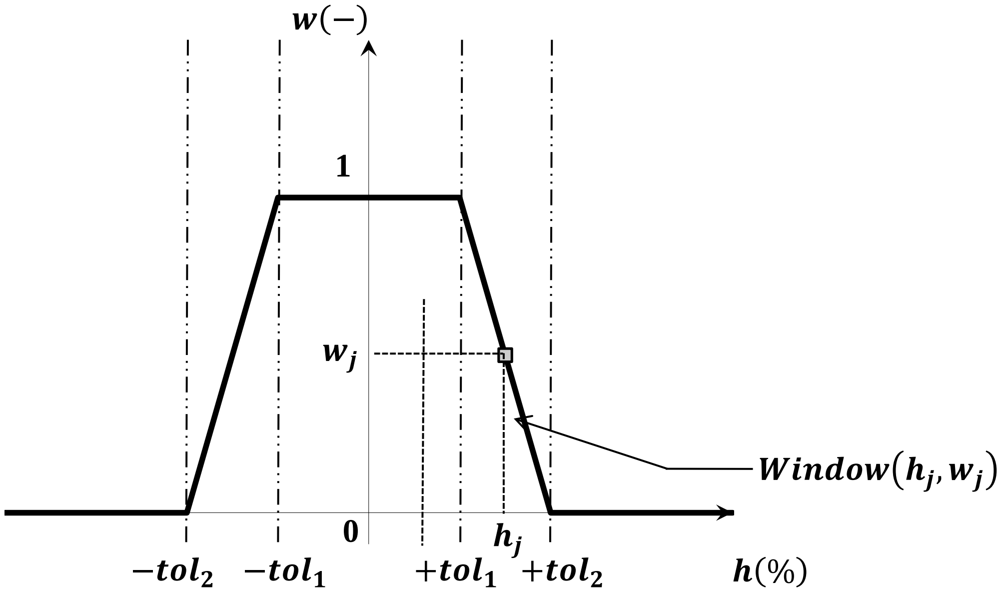
Then $w_j = 0$

where:

$$h_j = 100.\frac{M_{CO2,d,j} - M_{CO2,d,CC}(\bar{v}_j)}{M_{CO2,d,cc}(\bar{v}_j)}$$

Figure 5

Averaging window weighting function



6.2. Calculation of severity indices

The severity indices shall be calculated separately for the urban, rural and motorway categories:

$$\bar{h}_k = \frac{1}{N_k}\sum h_j \; k = u, r, m$$

and the complete trip:

$$\bar{h}_t = \frac{f_u \bar{h}_u + f_r \bar{h}_r + f_m \bar{h}_m}{f_u + f_r + f_m}$$

where f_u, f_r f_m are equal to 0.34, 0.33 and 0.33 respectively.

6.3. Calculation of emissions for the total trip

Using the weighted distance-specific emissions calculated under point 6.1, the distance-specific emissions in [mg/km] shall be calculated for the complete trip each gaseous pollutant in the following way:

$$M_{gas,d,t} = 1000.\frac{f_u . M_{gas,d,u} + f_r . M_{gas,d,r} + f_m . M_{gas,d,m}}{(f_u + f_r + f_m)}$$

And for particle number:

$$M_{PN,d,t} = \frac{f_u . M_{PN,d,u} + f_r . M_{PN,d,r} + f_m . M_{PN,d,m}}{(f_u + f_r + f_m)}$$

Where f_u, f_r f_m are respectively equal to 0.34, 0.33 and 0.33.

7. NUMERICAL EXAMPLES

7.1. Averaging window calculations

Table 1

Main calculation settings

$M_{CO2,ref}$ [g]	610
Direction for averaging window calculation	Forward
Acquisition Frequency [Hz]	1

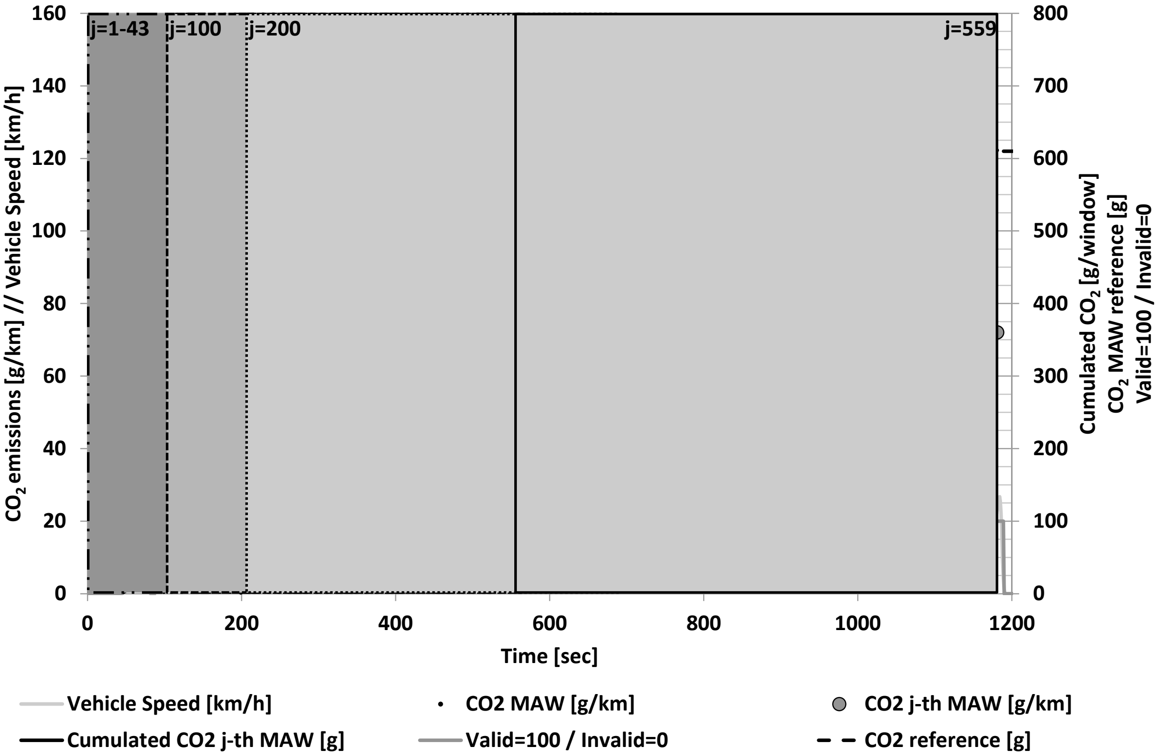
Figure 6 shows how averaging windows are defined on the basis of data recorded during an on-road test performed with PEMS. For sake of clarity, only the first 1200 seconds of the trip are shown hereafter.

Seconds 0 up to 43 as well as seconds 81 to 86 are excluded due to operation under zero vehicle speed.

The first averaging window starts at $t_{1,1}$ = 0s and ends at second $t_{2,1}$ = 524s (Table 3).

Figure 6

Instantaneous CO_2 emissions recorded during on-road test with PEMS as a function of time. Rectangular frames indicate the duration of the j^th window. Data series named “Valid=100 / Invalid=0” shows second by second data to be excluded from analysis.



7.2. Evaluation of windows

Table 2

Calculation settings for the CO_2 characteristic curve

CO_2 Low Speed WLTC x 1.2 (P_1) [g/km]	154
CO_2 High Speed WLTC x 1.1 (P_2) [g/km]	96
CO_2 Extra-High Speed WLTC x 1.05 (P_3) [g/km]	120

Reference Point		
P_1	$\overline{v_{P1}} = 19.0\ km/h$	$M_{CO_2,d,P_1} = 154\ g/km$
P_2	$\overline{v_{P2}} = 56.6\ km/h$	$M_{CO_2,d,P_2} = 96\ g/km$
P_3	$\overline{v_{P3}} = 92.3\ km/h$	$M_{CO_2,d,P_3} = 120\ g/km$

The definition of the CO_2 characteristic curve is as follows:

For the section (P_1, P_2):

$M_{CO_2,d}(\bar{v}) = a_1\bar{v} + b_1$

with

$$a_1 = (96 - 154)/(56.6 - 19.0) = -\frac{58}{37.6} = -1.543$$

and b_1 = 154 – (-1.543)x19.0 = 154 + 29.317 = 183.317

For the section (P_2, P_3):

$M_{CO_2,d}(\bar{v}) = a_2\bar{v} + b_2$

$$a_2 = (120 - 96)/(92.3 - 56.6) = \frac{24}{35.7} = 0.672$$

with

and b_2 = 96 – 0.672x56.6 = 96 – 38.035 = 57.965

Examples of calculation for the weighting factors and the window categorisation as urban, rural or motorway are:

For window #45:

$M_{CO2,\mathrm{d},45} = 122.62 g/km$

$\overline{v_{45}} = 38.12 km/h$

The average speed of the window is lower than 45 km/h, therefore it is an urban window.

For the characteristic curve:

$M_{CO_2,d,CC}(\overline{v_{45}}) = a_1\overline{v_{45}} + b_1 = -1.543x38.12 + 183.317 = 124.498 g/km$

Verification of:

$M_{CO2,\mathrm{d},CC}(\bar{v}_j).(1 - tol_1/100) \leq M_{CO2,\mathrm{d},j} \leq M_{CO2,\mathrm{d},CC}(\bar{v}_j).(1 + tol_1/100)$

$M_{CO2,\mathrm{d},CC}(\overline{v_{45}}).(1 - tol_1/100) \leq M_{CO2,\mathrm{d},45} \leq M_{CO2,\mathrm{d},CC}(\overline{v_{45}}).(1 + tol_1/100)$

$124.498\text{x}(1 - 25/100) \leq 122.62 \leq 124.498\text{x}(1 + 25/100)$

$93.373 \leq 122.62 \leq 155.622$

Leads to : $w_{45} = 1$

For window #556:

$M_{CO2,\text{d},556} = 72.15 g/km$

$\overline{v_{556}} = 50.12 km/h$

The average speed of the window is higher than 45 km/h but lower than 80 km/h, therefore it is a rural window.

For the characteristic curve:

$$M_{CO2,\text{d},CC}(\overline{v_{556}}) = a_1\overline{v_{556}} + b_1 = -1.543x50.12 + 183.317 = 105.982 g/km$$

Verification of:

$$M_{CO2,\text{d},CC}(\bar{v}_j).(1 - tol_2/100) \leq M_{CO2,\text{d},j} < M_{CO2,\text{d},CC}(\bar{v}_j).(1 - tol_1/100)$$

$$M_{CO2,\text{d},CC}(\bar{v}_{556}).(1 - tol_2/100) \leq M_{CO2,\text{d},556} < M_{CO2,\text{d},CC}(\bar{v}_{556}).(1 - tol_1/100)$$

$105.982\text{x}(1 - 50/100) \leq 72.15 < 105.982\text{x}(1 - 25/100)$

$52.991 \leq 72.15 < 79.487$

Leads to:

$$h_{556} = 100.\frac{M_{CO2,\text{d},556} - M_{CO2,\text{d},CC}(\bar{v}_{556})}{M_{CO2,\text{d},cc}(\bar{v}_{556})} = 100.\frac{72.15 - 105.982}{105.982} = -31.922$$

$w_{556} = k_{21}h_{556} + k_{22} = 0.04 * (-31.922) + 2 = 0.723$
$with\ k_{21} = 1/(tol_2 - tol_1) = 1/(50 - 25) = 0.04$

$$and\quad k_{22} = k_{12} = tol_2/(tol_2 - tol_1) = 50/(50 - 25) = 2$$

Table 3

Emissions numerical data

Window [#]	$t_{1,j}$ [s]	$t_{2,j} - \Delta t$ [s]	$t_{2,j}$ [s]	$M_{CO_2}(t_{2,j} - \Delta t) - M_{CO_2}(t_{1,j}) < M_{CO_2,ref}$ [g]	$M_{CO_2}(t_{2,j}) - M_{CO_2}(t$ [g]
1	0	523	524	609.06	610.22
2	1	523	524	609.06	610.22
…	…		…	…	…
43	42	523	524	609.06	610.22
44	43	523	524	609.06	610.22
45	44	523	524	609.06	610.22
46	45	524	525	609.68	610.86
47	46	524	525	609.17	610.34
…	…		…	…	…
100	99	563	564	609.69	612.74
…	…		…	…	…
200	199	686	687	608.44	610.01
…	…		…	…	…
474	473	1024	1025	609.84	610.60
475	474	1029	1030	609.80	610.49
	…		…	…	…
556	555	1173	1174	609.96	610.59
557	556	1174	1175	609.09	610.08
558	557	1176	1177	609.09	610.59
559	558	1180	1181	609.79	611.23

7.3. Urban, rural and motorway windows - Trip completeness

In this numerical example, the trip consists of 7036 averaging windows. Table 5 lists the number of windows classified in urban, rural and motorway according to their average vehicle speed and divided in regions with respect to their distance to the CO_2 characteristic curve. The trip is complete since it comprises at least 15% of urban, rural and motorway windows out of the total number of windows. In addition the trip is characterized as normal since at least 50% of the urban, rural and motorway windows are within the primary tolerances defined for the characteristic curve.

Table 4.

Verification of trip completeness and normality

Driving Conditions	Numbers	Percentage of windows
All Windows		
Urban	1909	1909/7036*100=27.1 >15
Rural	2011	2011/7036*100=28.6 >15
Motorway	3116	3116/7036*100=44.3 >15
Total	1909+2011+3116=7036	
Normal Windows		
Urban	1514	1514/1909*100=79.3 >50
Rural	1395	1395/2011*100=69.4 >50
Motorway	2708	2708/3116*100=86.9 >50
Total	1514+1395+2708=5617	