TFVS Cross Matrix Subgroup

Rotranomo Model calculation results

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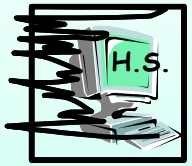
Overview

- **Rotranomo Model**
- **HBEFA Traffic situation schema**
- **Sound emission stages**
- **Results for the HBEFA cycles**
- **Results for different driving behaviour**

Rotranomo Model



The Rotranomo model was developed within the project "Development of a Microscopic Road Traffic Noise Model for the Assessment of Noise Reduction Measures" funded by the European Community under the 'Competitive and Sustainable Growth' Programme.

The model calculates an instantaneous pass by level for different vehicle subcategories and emission stages on the basis of second by second vehicle speed traces separately for tyre/road and propulsion sound levels.

The model was developed in 2003 to 2005 but was updated in later projects in order to cover also the 3 emission stages defined in 2009/661/EU and 540/2014/EU, phase 1 to phase 3.

Rotranomo Model

The Rotranomo model is described in the following documents:

- **[1], Rotranomo_D42_WP40_drivetrain_model_1m.doc**
- **[2], Rotranomo_D44_WP40_noise_emission_model_1.doc**
- **[3], Rotranomo_D43_ WP40_calibration_measurements_1.doc**

HBEFA traffic situation schema

- **The HBEFA traffic situation schema is summarized in the following table which was copied from the HBEFA model:**

Overview Traffic Situations

Area	Road type	Levels of service	Speed Limit [km/h] 30	40	50	60	70	80	90	100	110	120	130	>130
Rural	Motorway-Nat.	5 levels of service												
	Semi-Motorway	5 levels of service												
	TrunkRoad/Primary-Nat.	5 levels of service												
	Distributor/Secondary	5 levels of service												
	Distributor/Secondary(sinuous)	5 levels of service												
	Local/Collector	5 levels of service												
	Local/Collector(sinuous)	5 levels of service												
	Access-residential	5 levels of service												
Urban	Motorway-Nat.	5 levels of service												
	Motorway-City	5 levels of service												
	TrunkRoad/Primary-Nat.	5 levels of service												
	TrunkRoad/Primary-City	5 levels of service												
	Distributor/Secondary	5 levels of service												
	Local/Collector	5 levels of service												
	Access-residential	5 levels of service												

Assigned Fleet Compositions
- = Motorway
- = Rural
- = Urban

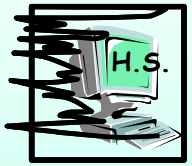
Return

Table 1

HBEFA traffic situation schema

- **The calculation of emission factors for pollutant emissions is based on specific driving cycles (second by second vehicle speed pattern) per traffic situation.**
- **These driving cycles were used as basis for sound emission calculations using the Rotranomo model.**

Sound emission stages



- **The following car subcategories and sound emission stages are specified in the Rotranomo model:**
  - **Car subcategories:**

    Petrol <1,4 l, Petrol 1,4-2 l, Petrol >2 l, Petrol >2 l, high perf., Diesel <2 l and Diesel >2 l

  - **Sound emission stages:**

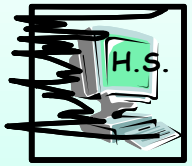
    up to 1981, 1982 to 1988, 1989 to 1995, 1996 to 2016,

    2009/661/EU and 540/2014/EU, phase 1, 2017 to 2021,

    2009/661/EU and 540/2014/EU, phase 2, 2022 to 2025,

    2009/661/EU and 540/2014/EU, phase 3, from 2026.

Results for the HBEFA cycles



- The Rotranomo model was applied on the following car subcategories:
  - Petrol 1,4-2 l,
  - Petrol >2 l, high perf.,
  - Diesel >2 l
- The following figures (fig 1 to 3) show the average total sound emission versus vehicle speed for the above listed car subcategories.
- The road surface for all cases is stone mastic asphalt 0/11.
- Figure 4 shows the two dimensional distribution of acceleration and vehicle speed for the sum of all HBEFA 4 cycles.

Petrol 1,4-2 l

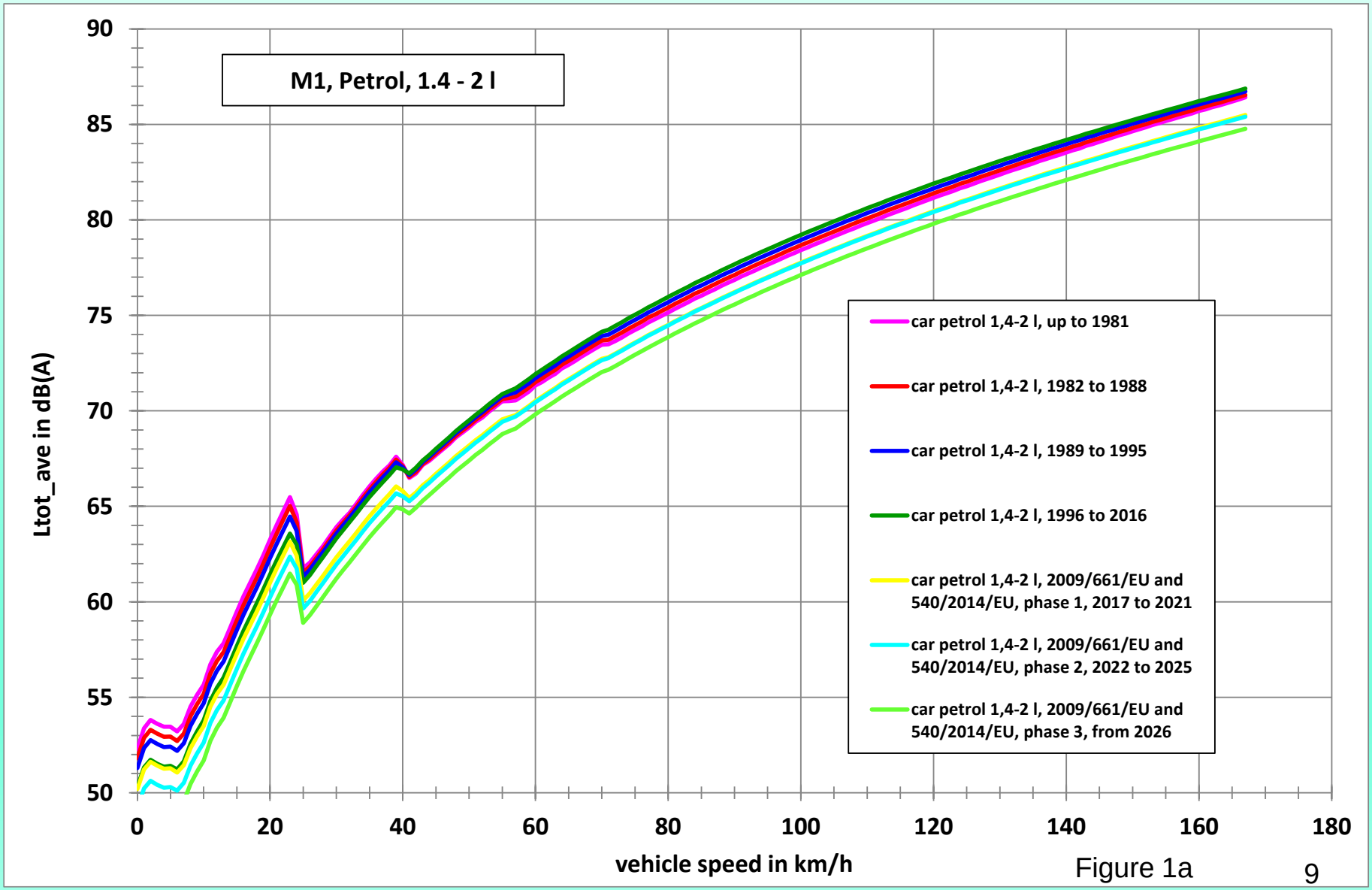


Figure 1a

Petrol 1,4-2 l

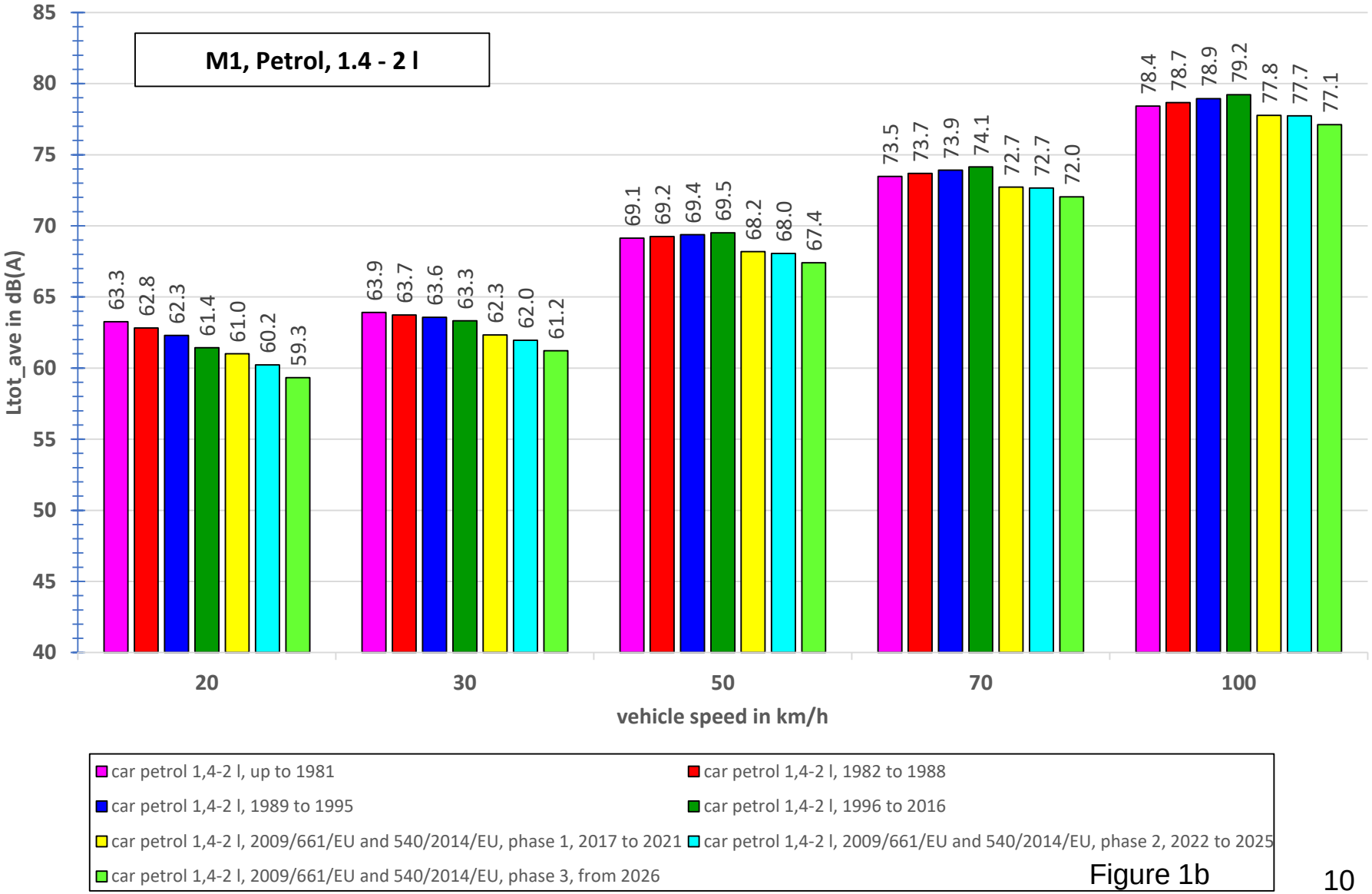


Figure 1b

Diesel >2 l

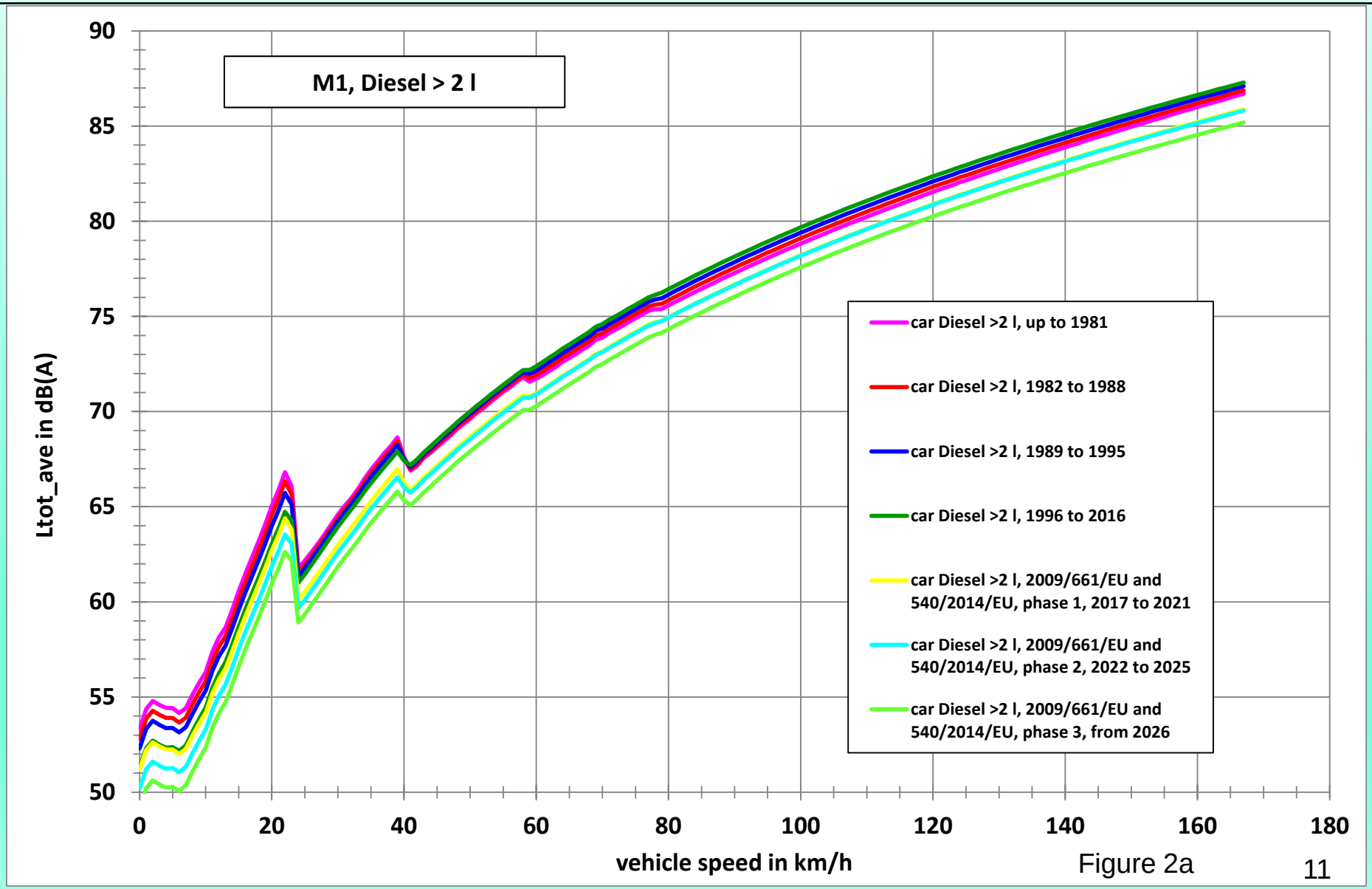


Figure 2a

Diesel >2 l

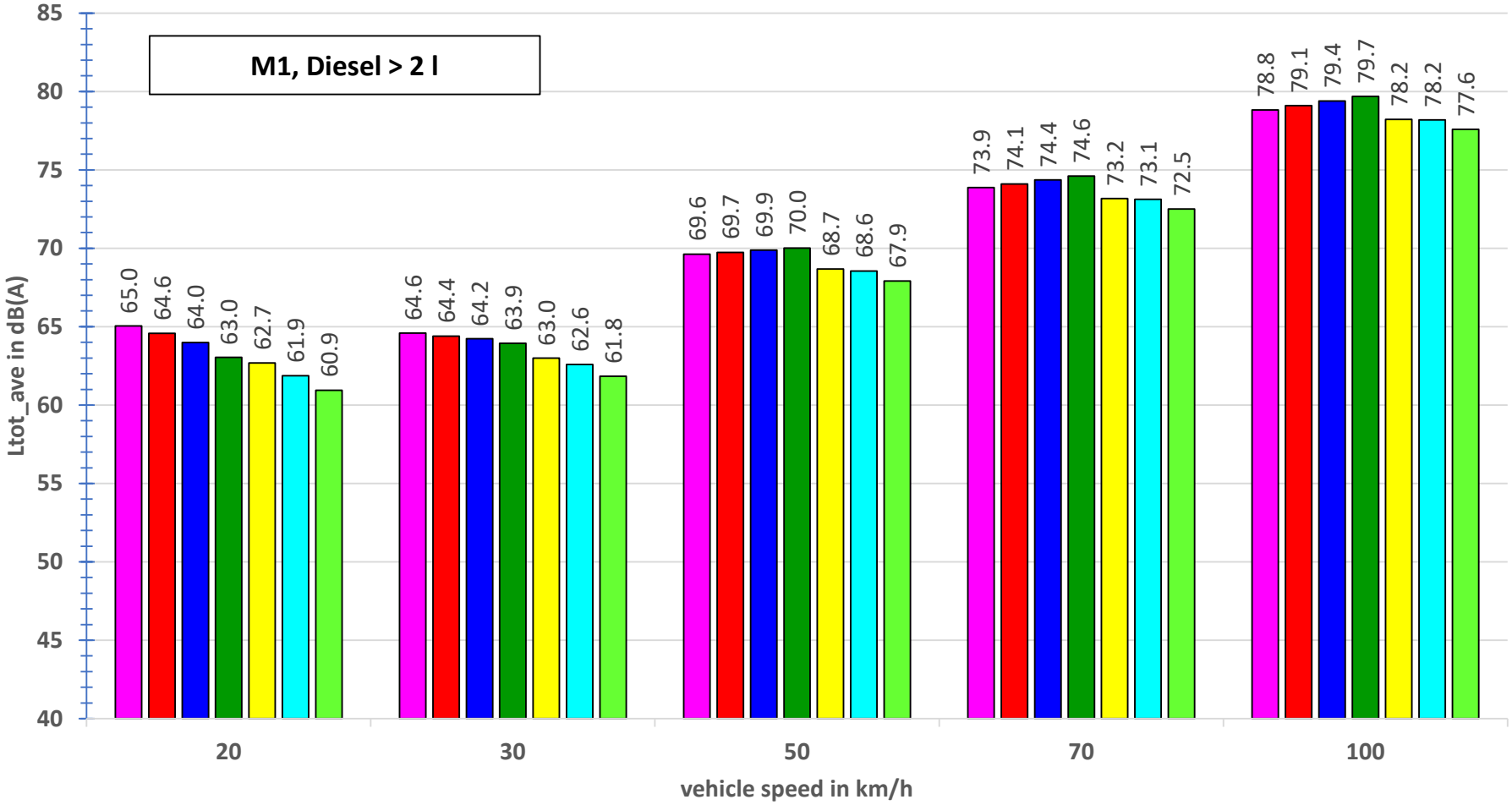


Figure 2b

Petrol >2 l, high performance

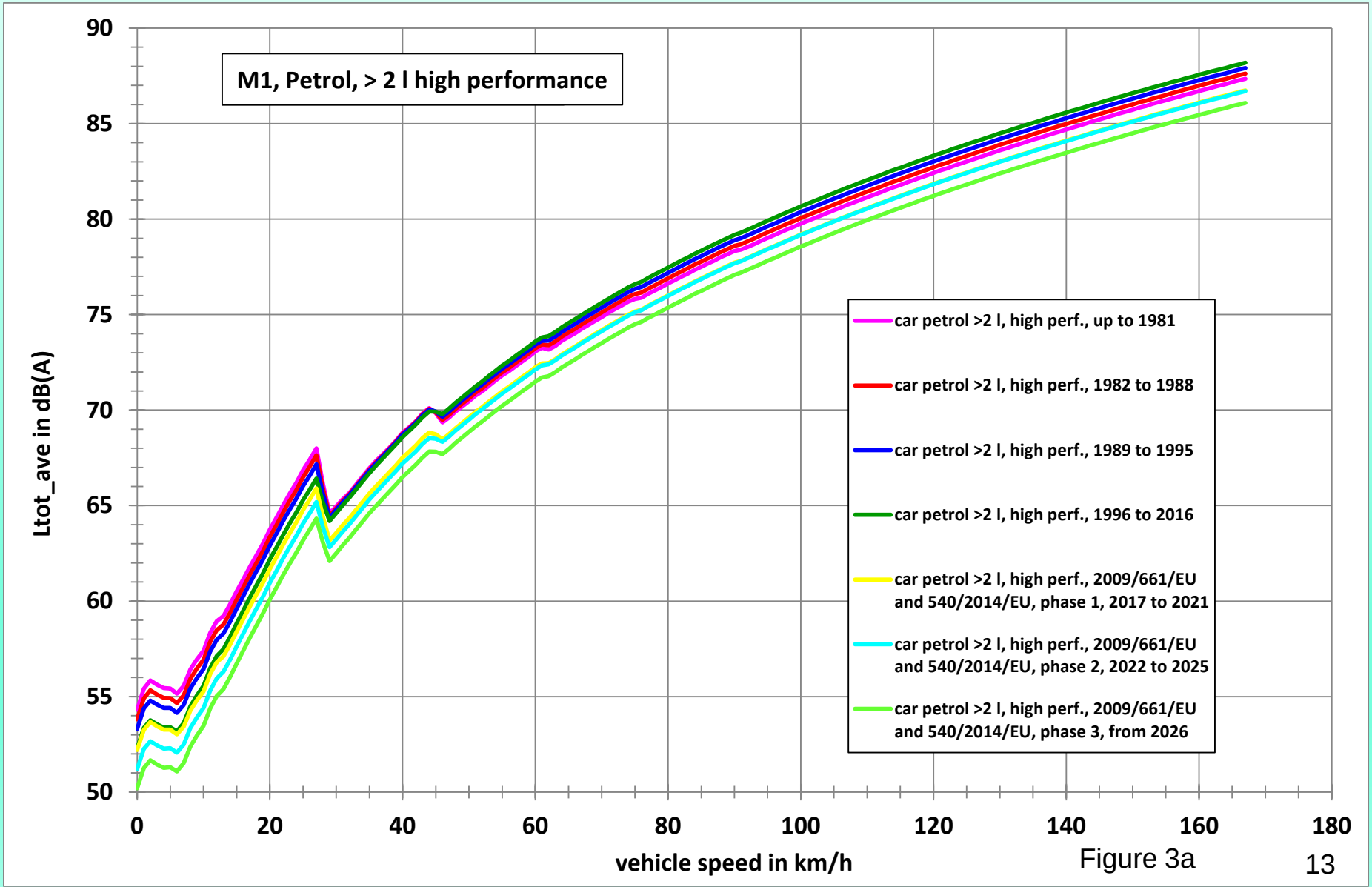


Figure 3a

Petrol >2 l, high performance

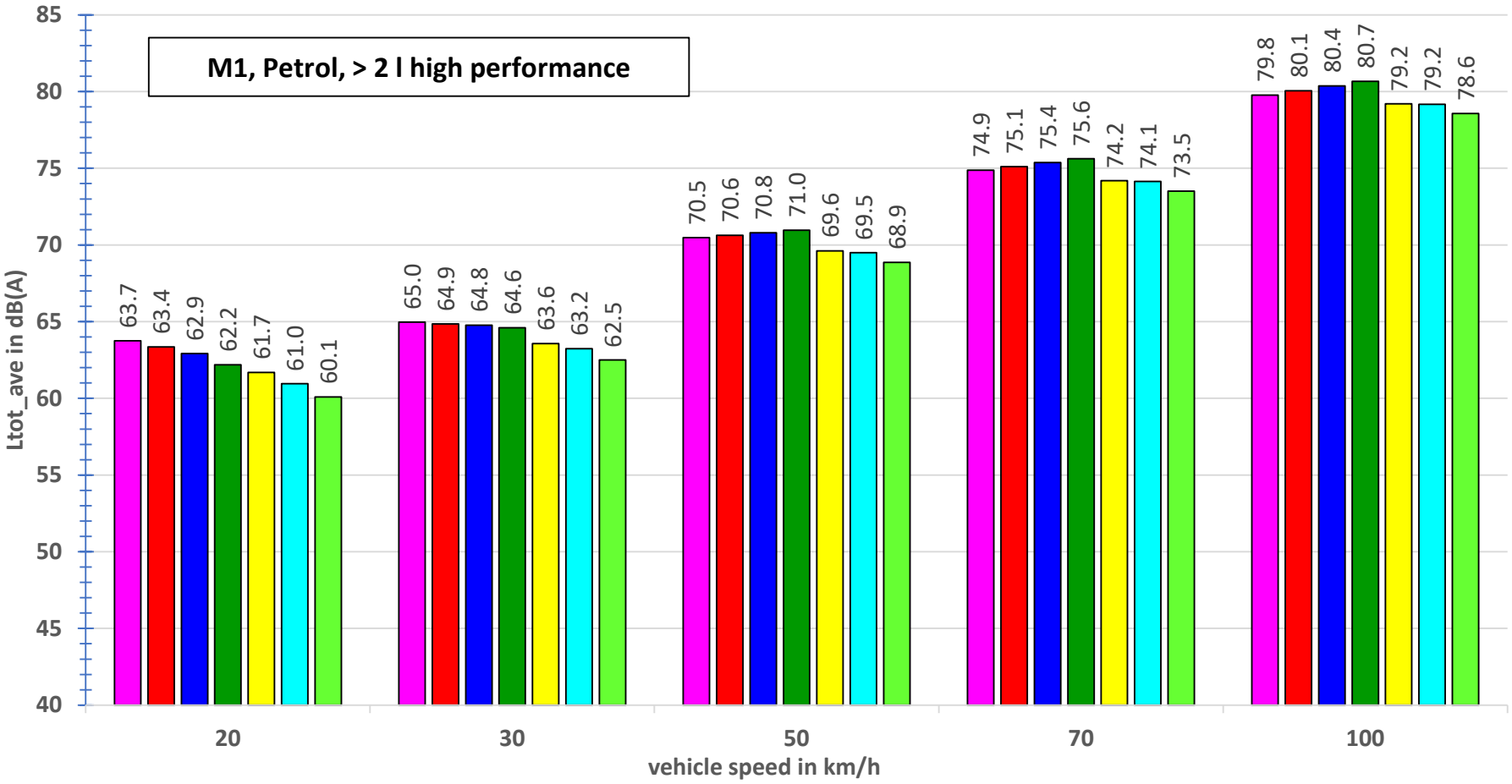


Figure 3b

a-v distribution of all HBEFA 4 cycles

all HBEFA 4 cycles

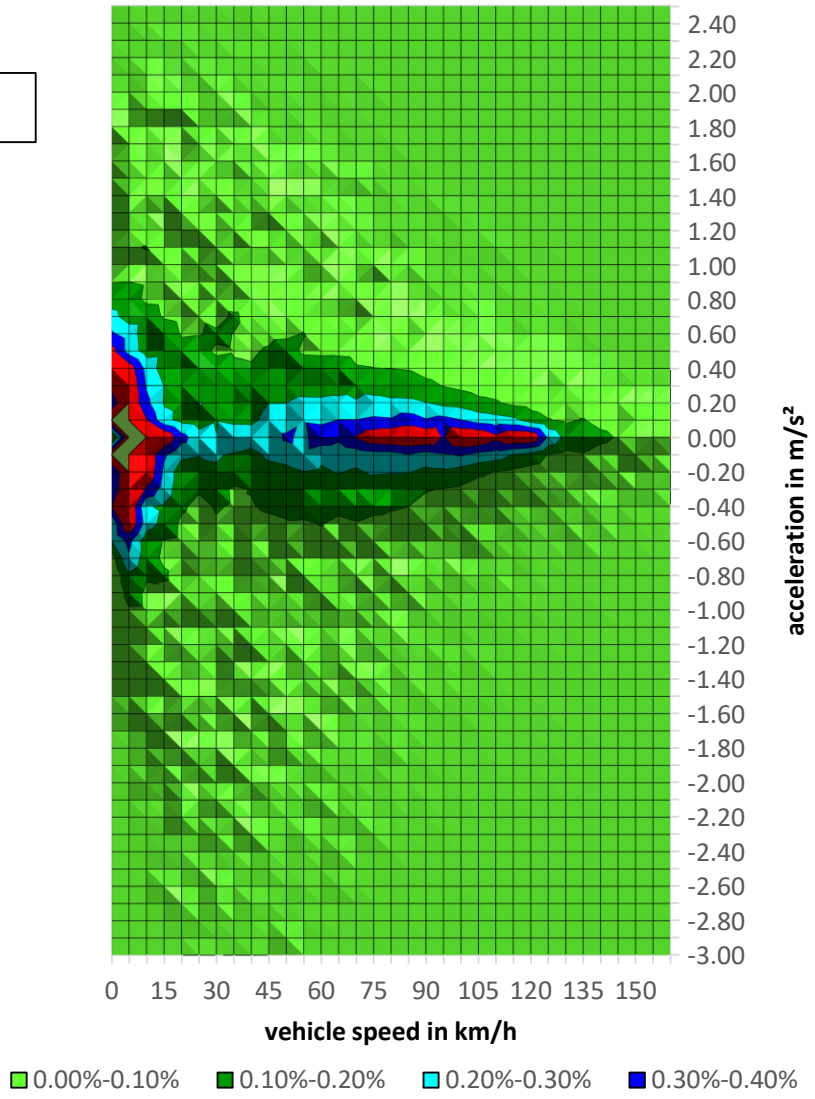
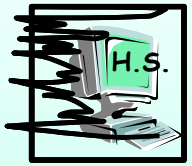


Figure 4

Results for the HBEFA cycles



- **The following figures show the distribution of Ltot (a series) and Lprop (b series) as function of acceleration and vehicle speed.**
- **Figures 5 to 7 show the results for vehicles of the emission stage 1996 to 2016, figures 8 to 10 show the results for vehicles of the emission stage 2009/661/EU and 540/2014/EU, phase 3, from 2026 on.**
- **The road surface for all cases is stone mastic asphalt 0/11.**

Emission stage 1996 to 2016

Cars, petrol, 1.4 - 2.0 l eng cap., 1996 to 2016, mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles

Ltot in dB(A), 7.5 m distance

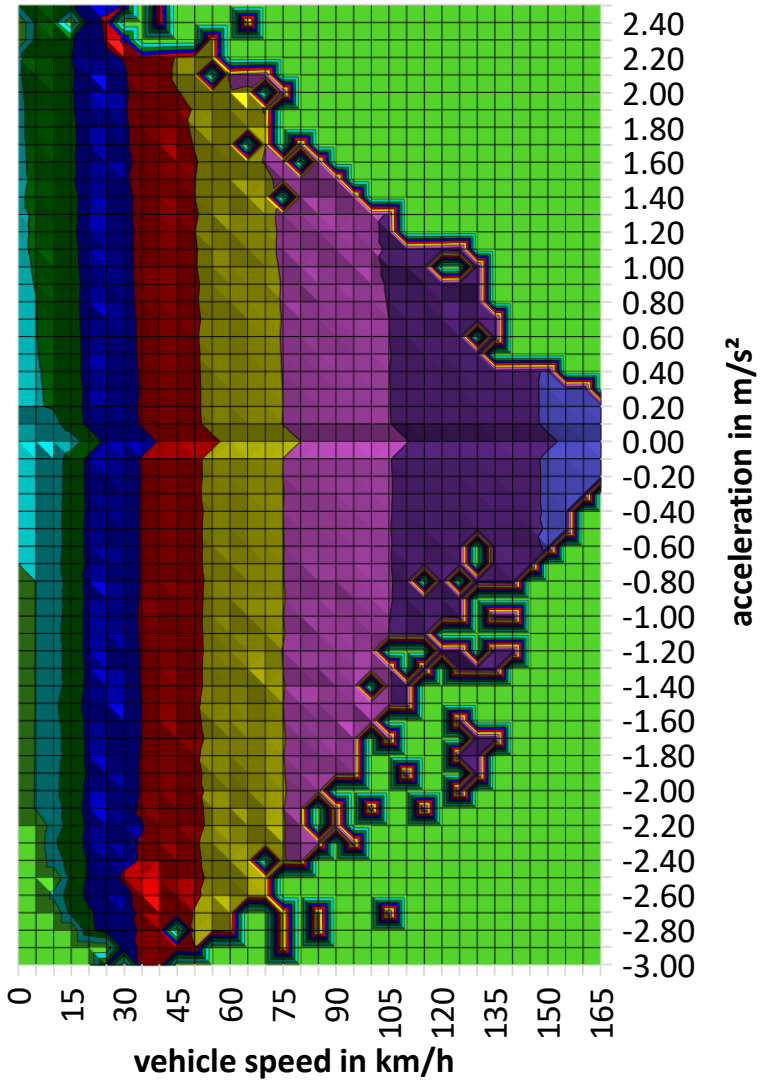


Figure 5a

Emission stage 1996 to 2016

Cars, petrol, 1.4 - 2.0 l eng cap., 1996 to 2016, mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles

Lprop in dB(A), 7.5 m distance

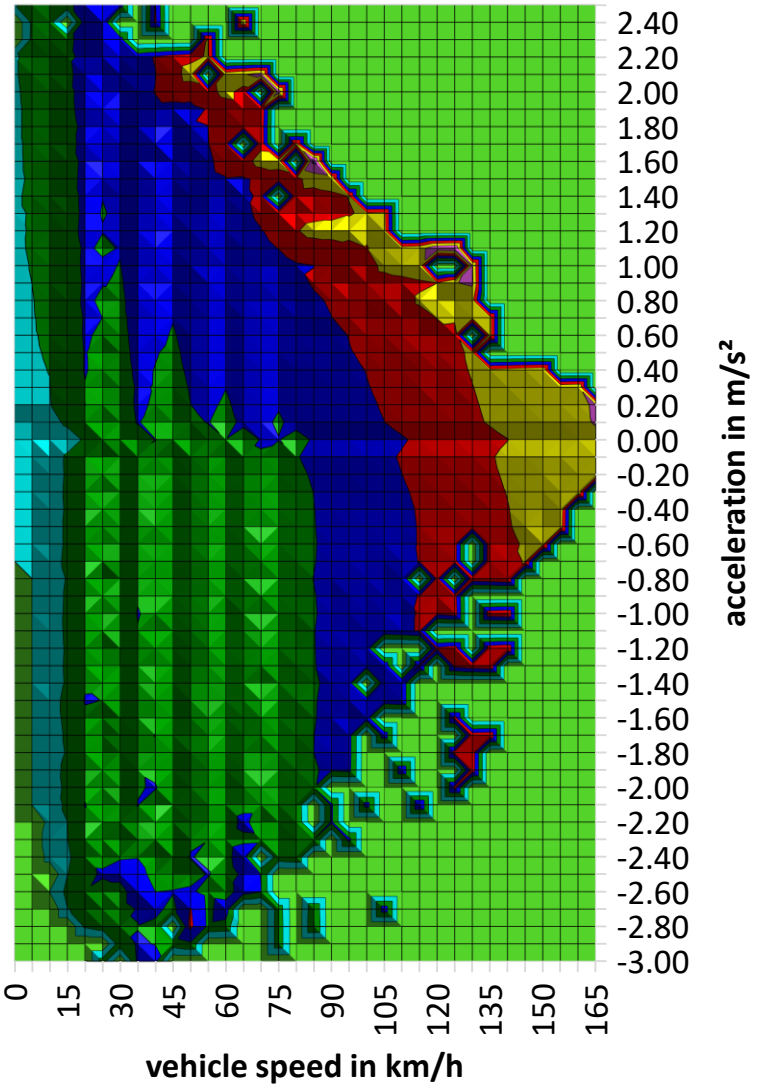


Figure 5b

Emission stage 1996 to 2016

Cars, Diesel, > 2.0 l eng cap., 1996 to 2016, mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles

Ltot in dB(A), 7.5 m distance

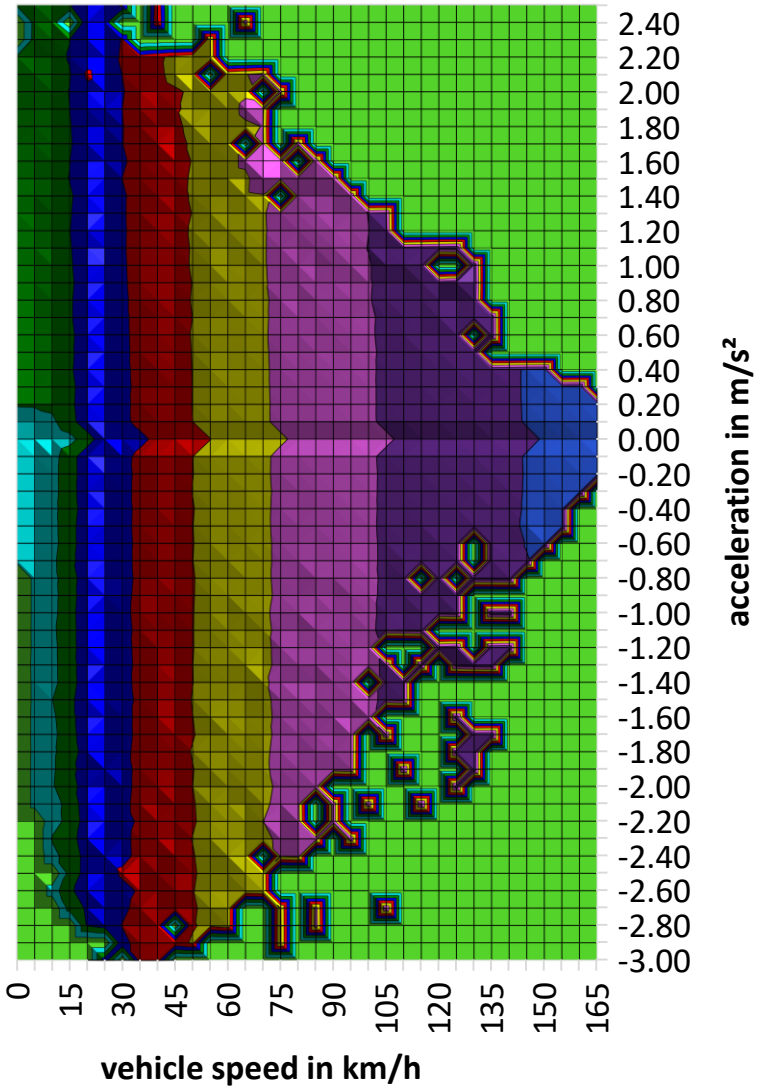


Figure 6a

Emission stage 1996 to 2016

Cars, Diesel, > 2.0 l eng cap., 1996 to 2016, mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles

Lprop in dB(A), 7.5 m distance

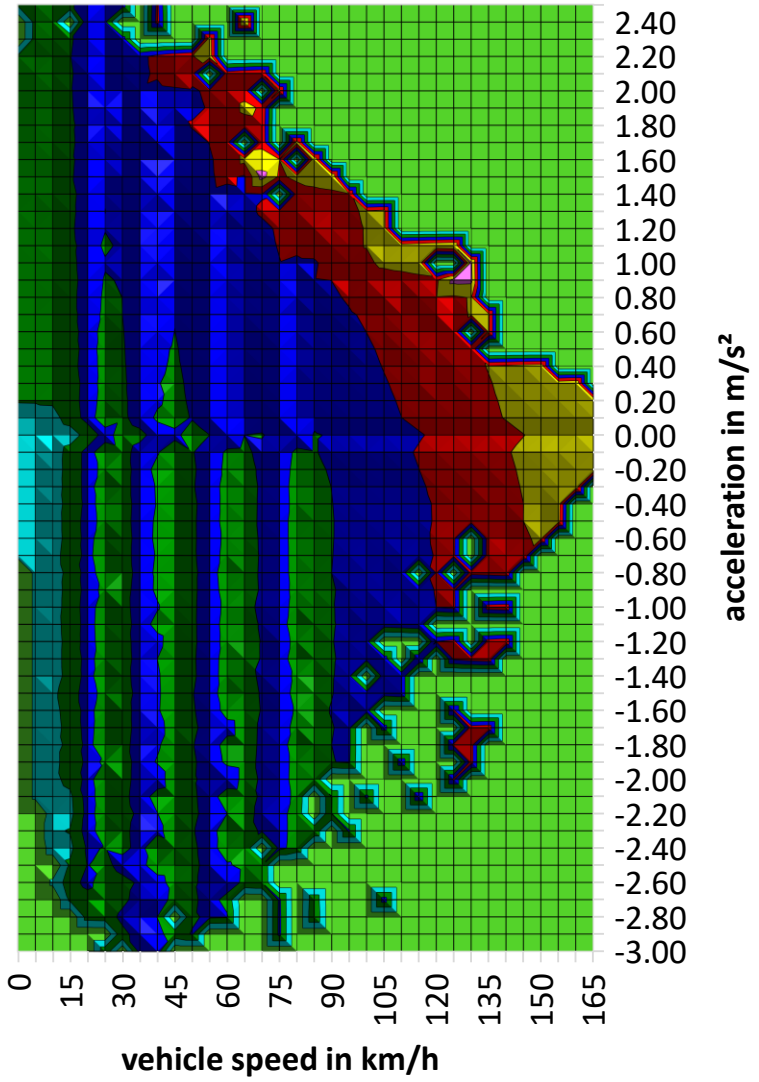


Figure 6b

Emission stage 1996 to 2016

Cars, petrol, > 2.0 l eng cap., high performance,
1996 to 2016, mastic asphalt 0/11,
second by second data all HBEFA 4.1 cycles

Ltot in dB(A), 7.5 m distance

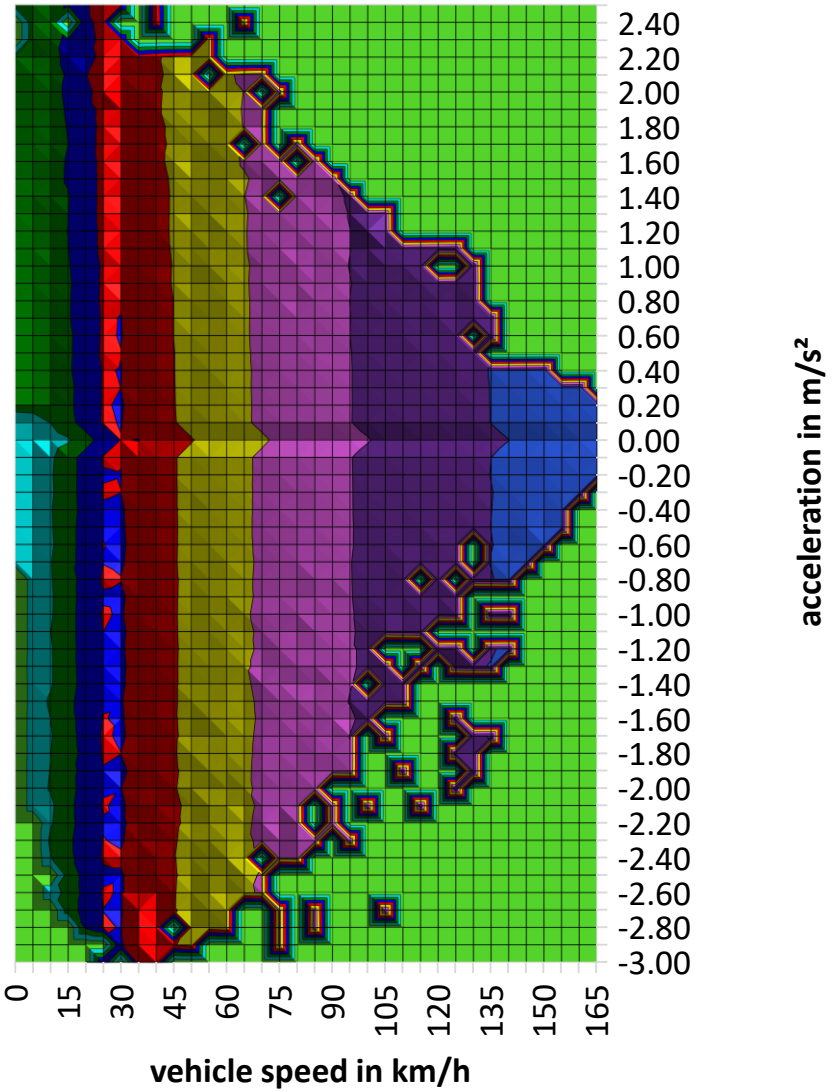


Figure 7a

Emission stage 1996 to 2016

Cars, petrol, > 2.0 l eng cap., high performance,
1996 to 2016, mastic asphalt 0/11,
second by second data all HBEFA

Lprop in dB(A), 7.5 m distance

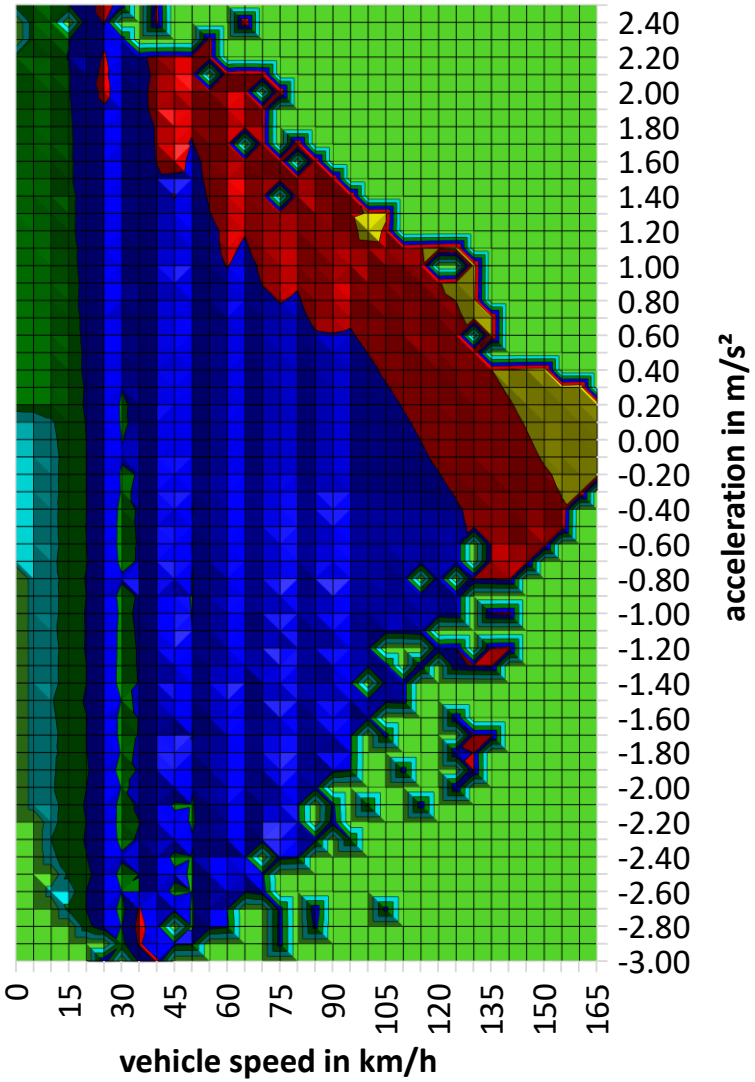


Figure 7b

Emission stage 2009/661/EU and 540/2014/EU, phase 3, from 2026

Cars, petrol, 1.4 - 2.0 l eng cap., mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles, 2009/661/EU and 540/2014/EU, phase 3, 2022 to 2026

Ltot in dB(A), 7.5 m distance

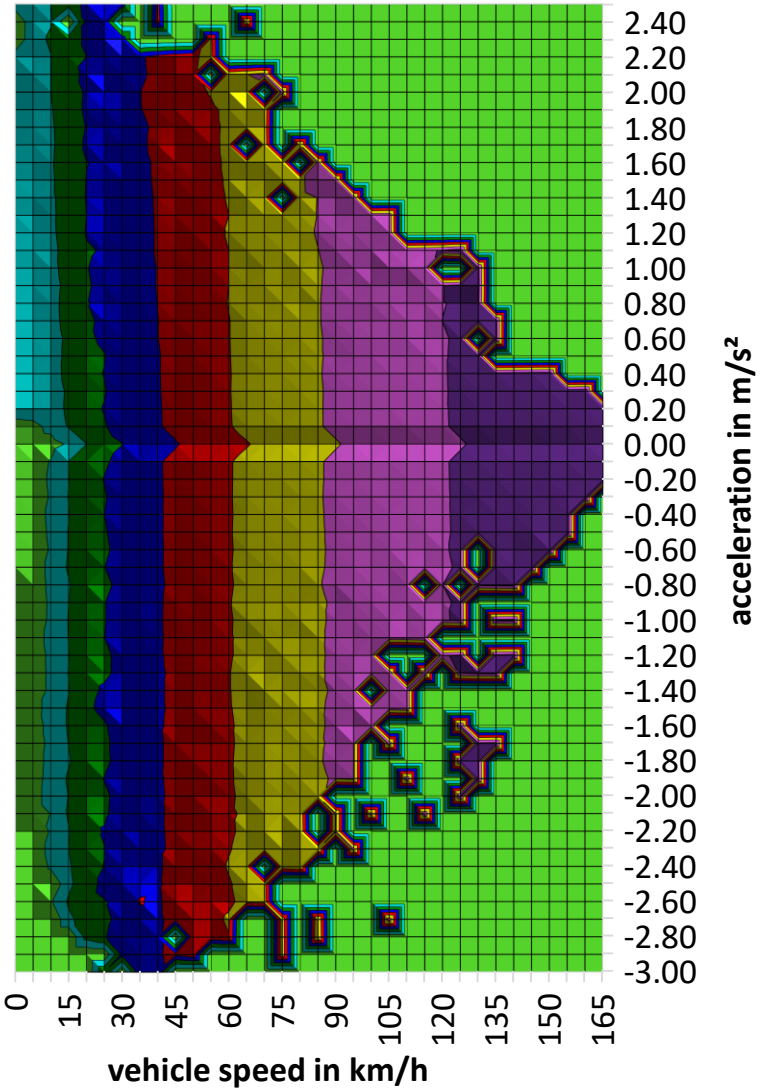


Figure 8a

Emission stage 2009/661/EU and 540/2014/EU, phase 3, from 2026

Cars, petrol, 1.4 - 2.0 l eng cap., mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles, 2009/661/EU and 540/2014/EU, phase 3, 2022 to 2026

Lprop in dB(A), 7.5 m distance

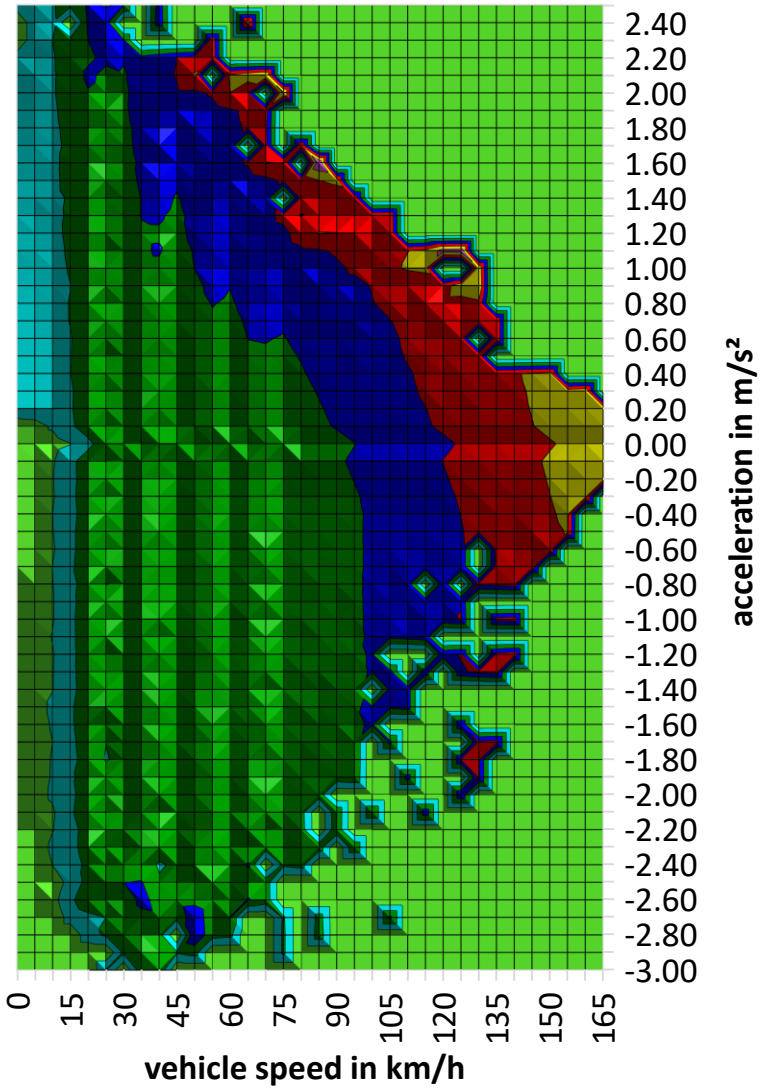


Figure 8b

Emission stage 2009/661/EU and 540/2014/EU, phase 3, from 2026

Cars, Diesel, > 2.0 l eng cap., mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles, 2009/661/EU and 540/2014/EU, phase 3, 2022 to 2026

Ltot in dB(A), 7.5 m distance

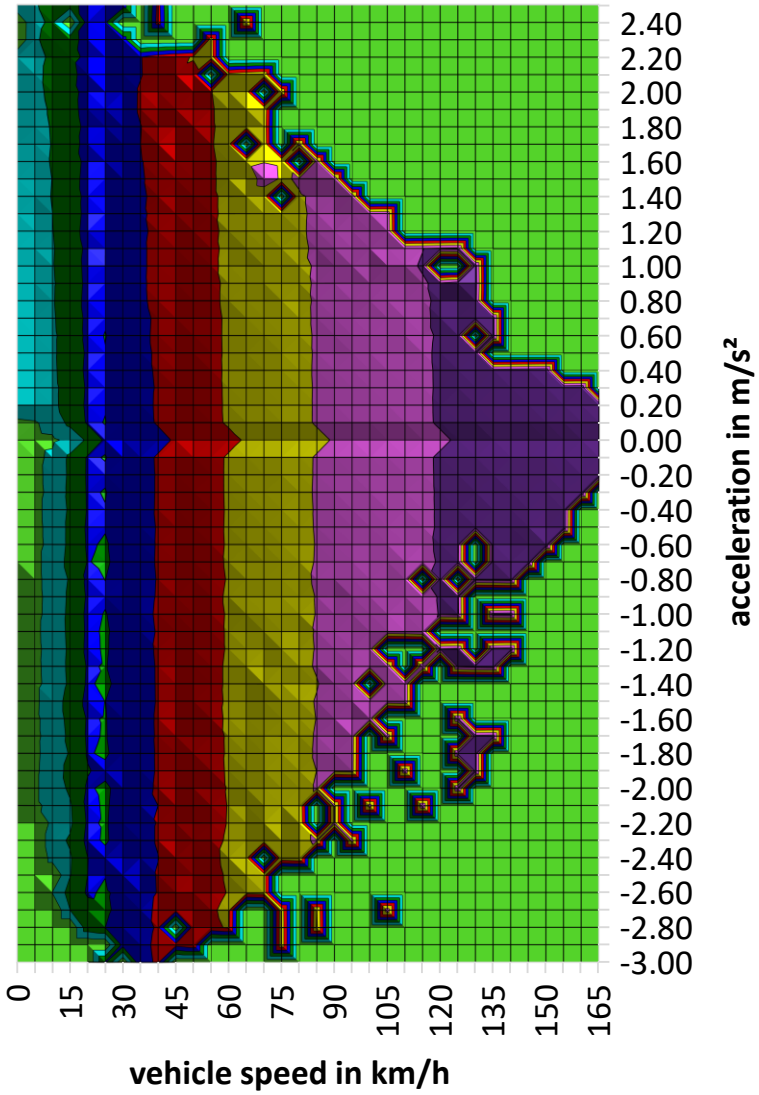


Figure 9a

Emission stage 2009/661/EU and 540/2014/EU, phase 3, from 2026

Cars, Diesel, > 2.0 l eng cap., mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles, 2009/661/EU and 540/2014/EU, phase 3, 2022 to 2026

Lprop in dB(A), 7.5 m distance

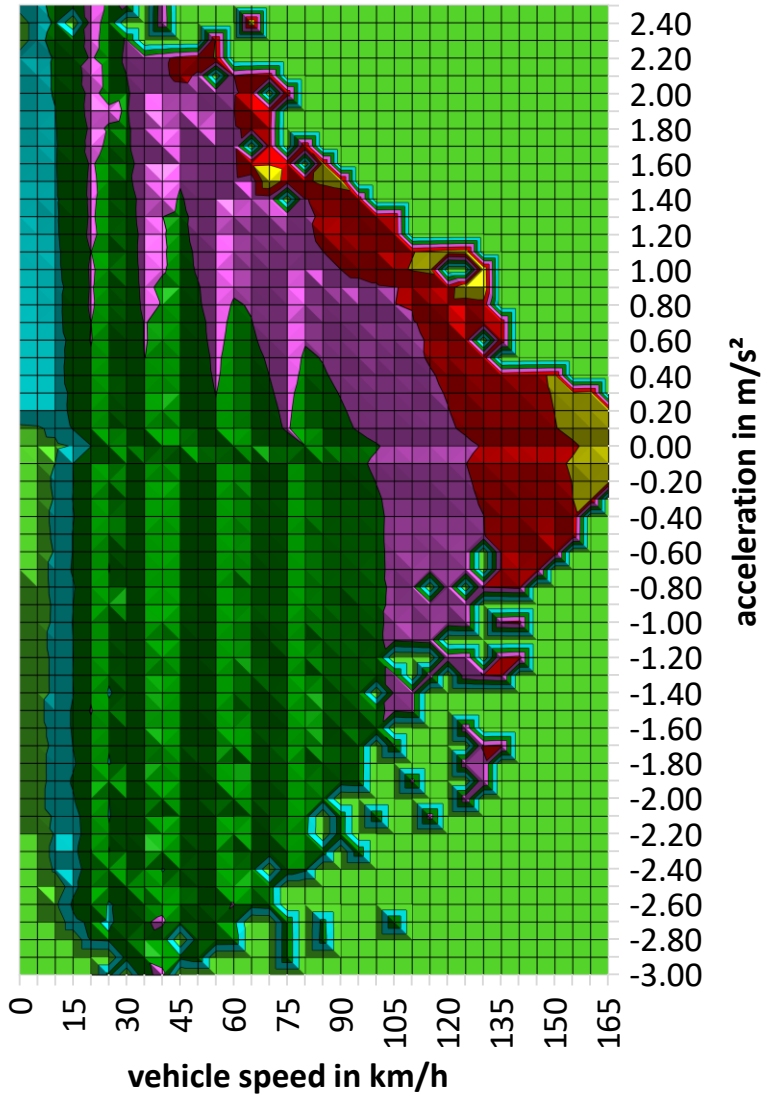


Figure 9b

Emission stage 2009/661/EU and 540/2014/EU, phase 3, from 2026

Cars, petrol, > 2.0 l eng cap., high performance,
mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles, 2009/661/EU and 540/2014/EU, phase 3, from 2026

Ltot in dB(A), 7.5 m distance

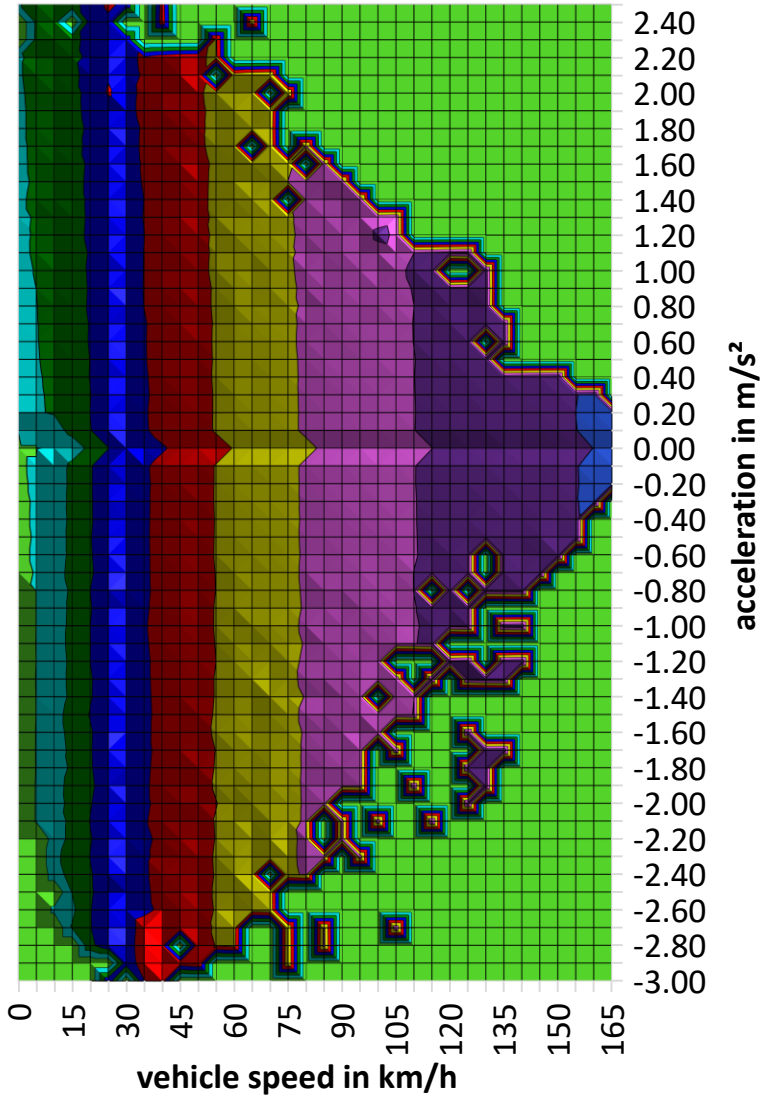


Figure 10a

Emission stage 2009/661/EU and 540/2014/EU, phase 3, from 2026

Cars, petrol, > 2.0 l eng cap., high performance,
mastic asphalt 0/11, second by second data all HBEFA 4.1 cycles, 2009/661/EU and 540/2014/EU, phase 3, from 2026

Lprop in dB(A), 7.5 m distance

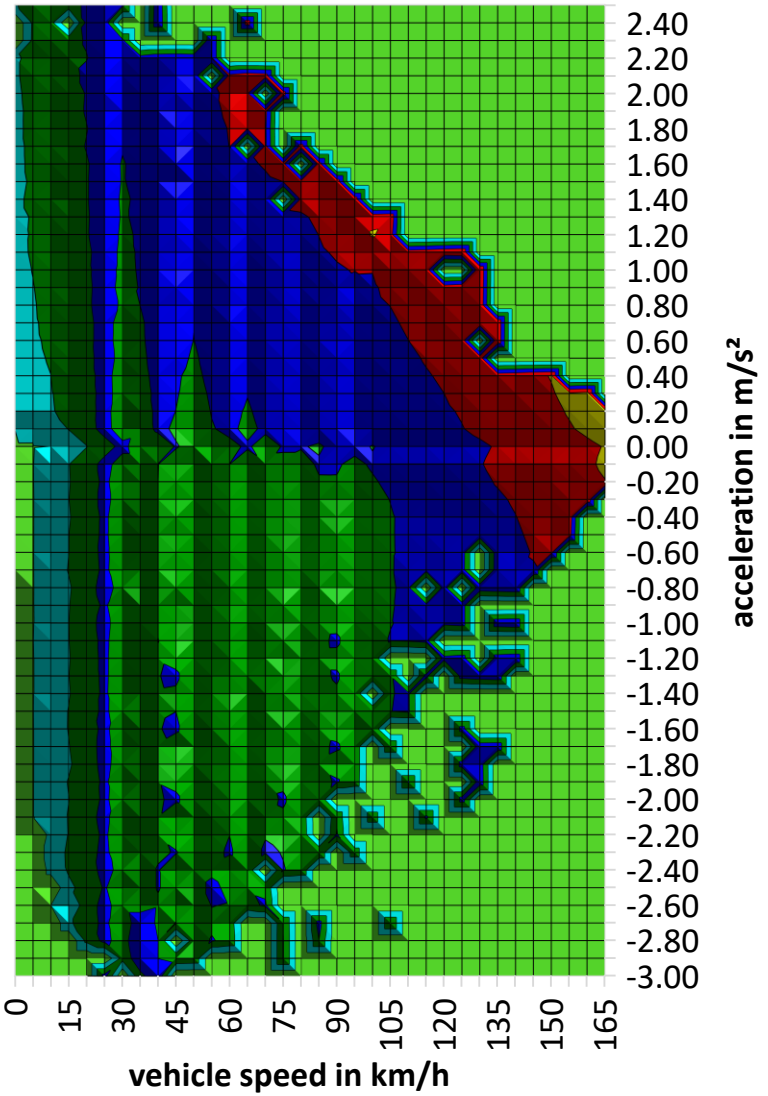
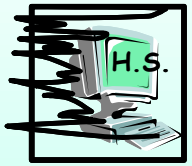


Figure 10b

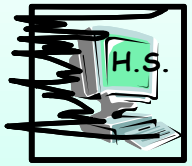
Results for the HBEFA cycles



The following conclusions can be drawn from the results:

- **The sound emission decreases from older to jounger or future emission stages at vehicle speeds of 20 and 30 km/h (below 50 km/h). The differences are about 4 dB at 20 km/h and between 2.5 to 3.1 dB at 30 km/h.**
- **Tyre/road sound emission is the dominant sound source from 50 km/h on.**
- **And since the vehicles got wider and bigger tyres with higher speed indices from emission stage to emission stage the total sound emission increased from the oldest stage to the 1996 to 2016 stage.**

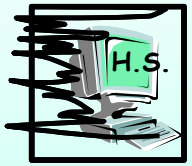
Results for the HBEFA cycles



The following conclusions can be drawn from the results (continued):

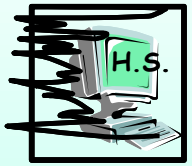
- **From this stage on the total sound emission decreases with the emission stages but the difference between the 2009/661/EU and 540/2014/EU, phase 3, from 2026 stage and the 1996 to 2016 stage is only 2.1 dB.**
- **The difference between the 3 vehicle subcategories are almost independent of the vehicle speed in the order of 1.5 dB.**
- **But one has to bare in mind that the HBEFA 4 cycles represent average driving behaviour and the cycles are the same for all vehicle subcategories.**

Results for different driving behaviour



- **In real traffic the driven cycles are influenced by the power to mass ratio to a certain extend which can lead to higher differences between the subcategories.**
- **In order to demonstrate the influence of different driving behaviour the Rotranomo model was also applied to a dataset of driving cycles collected on two different routes (urban and suburban) with 10 different vehicles ranging from subcompact cars to high performance or sport cars (rated power ranging from 40 kW to 210 kW).**

Results for different driving behaviour

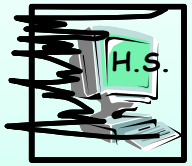


- **All cars were driven applying the following 3 driving behaviour styles:**
  - **Economical,**
  - **Average,**
  - **Aggressive.**
- **The results for a subcompact car (40 kW), a medium sized car (90 kW) and a high performance car (210 kW) are shown in the following figures.**
- **The results for both routes were merged.**
- **The results represent the current sound emission stage: 2009/661/EU and 540/2014/EU, phase 2, 2022 to 2025.**

Results for different driving behaviour

- **A comparison with the results for the HBEFA 4 cycles for a mid size car of this sound emission stage is shown in figure 24.**

Vehicle speed distributions



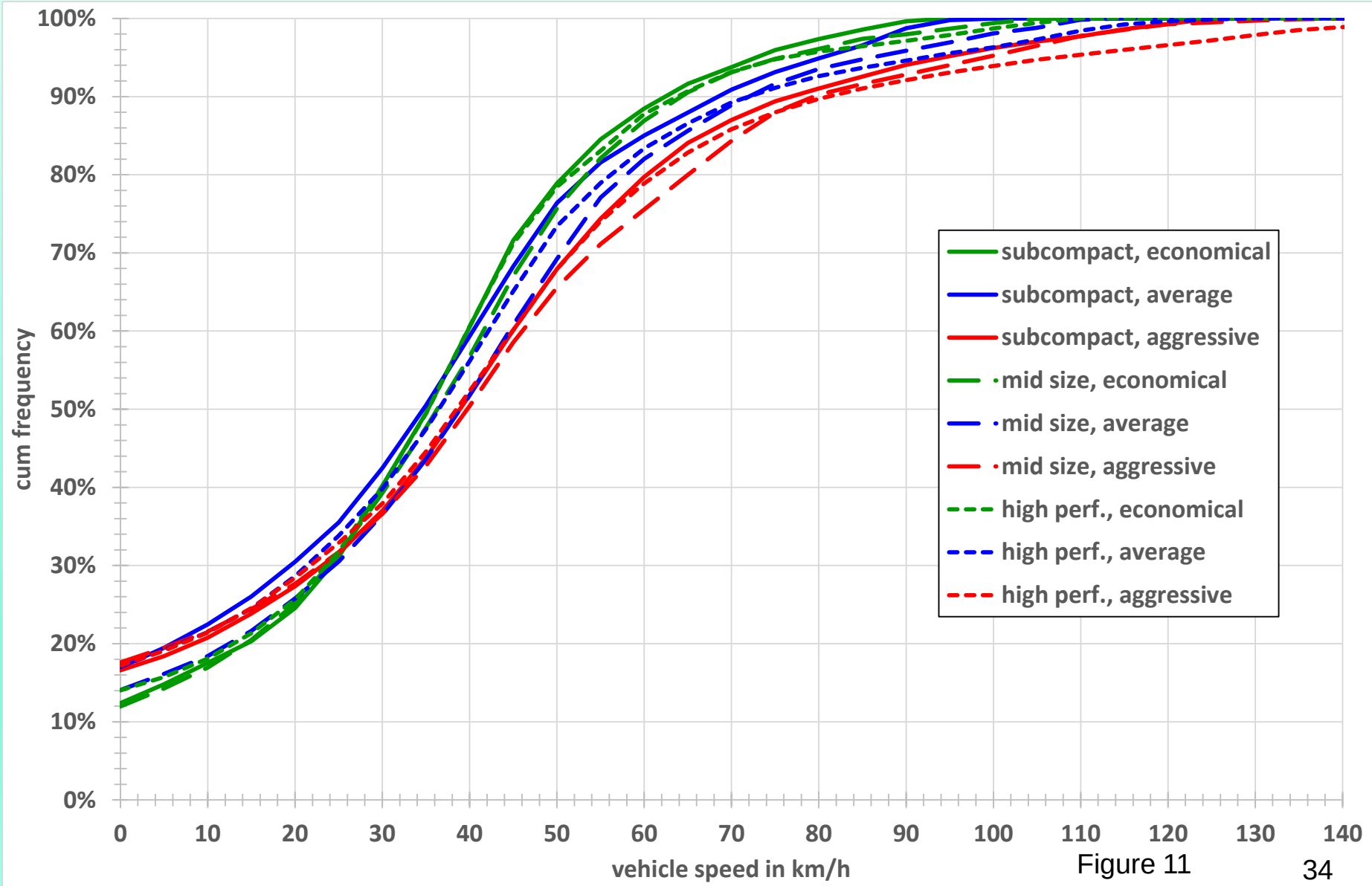


Figure 11

Acceleration distributions

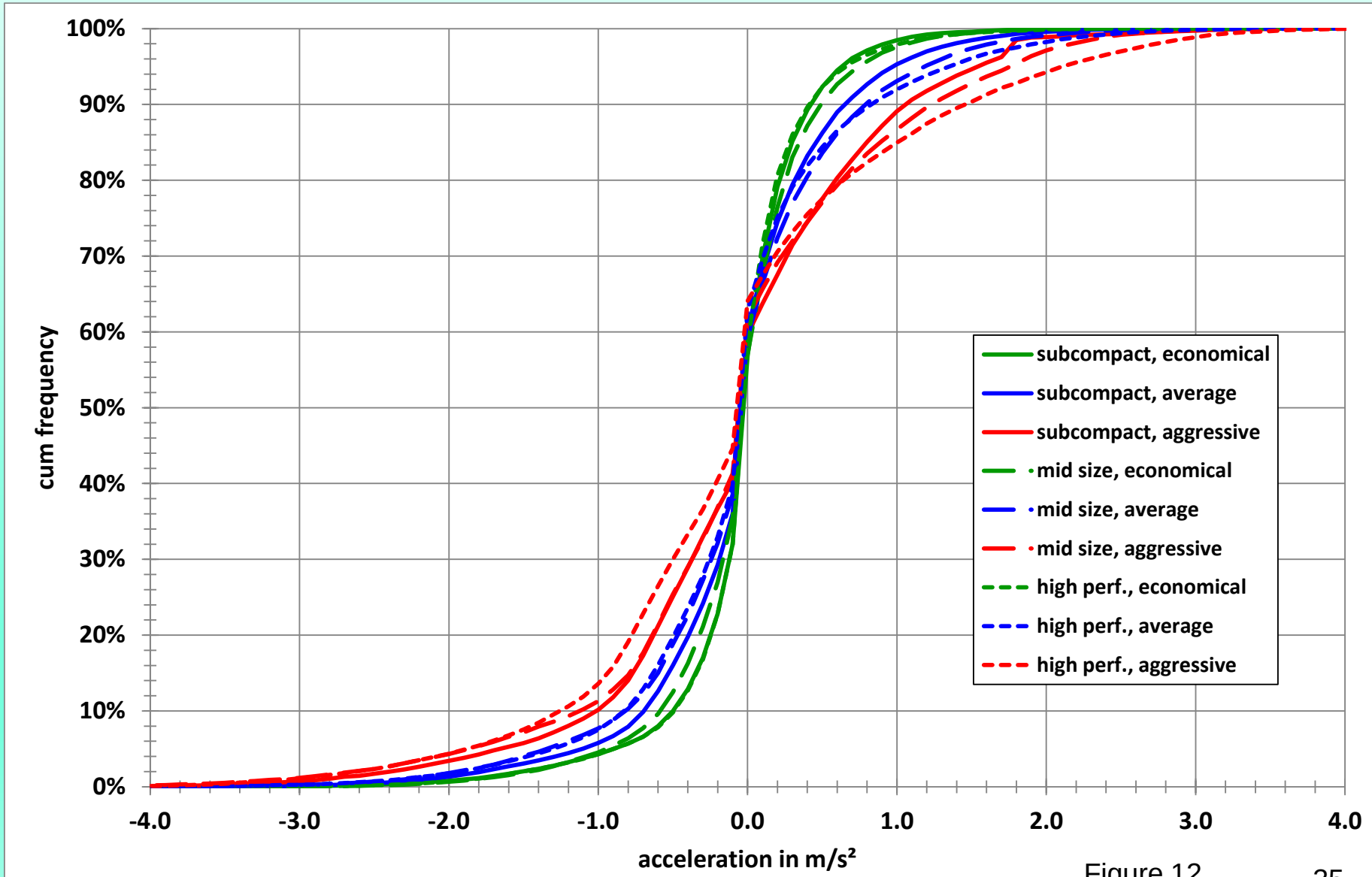
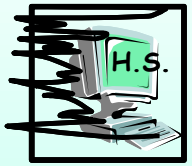


Figure 12

Average pos. acceleration vs speed



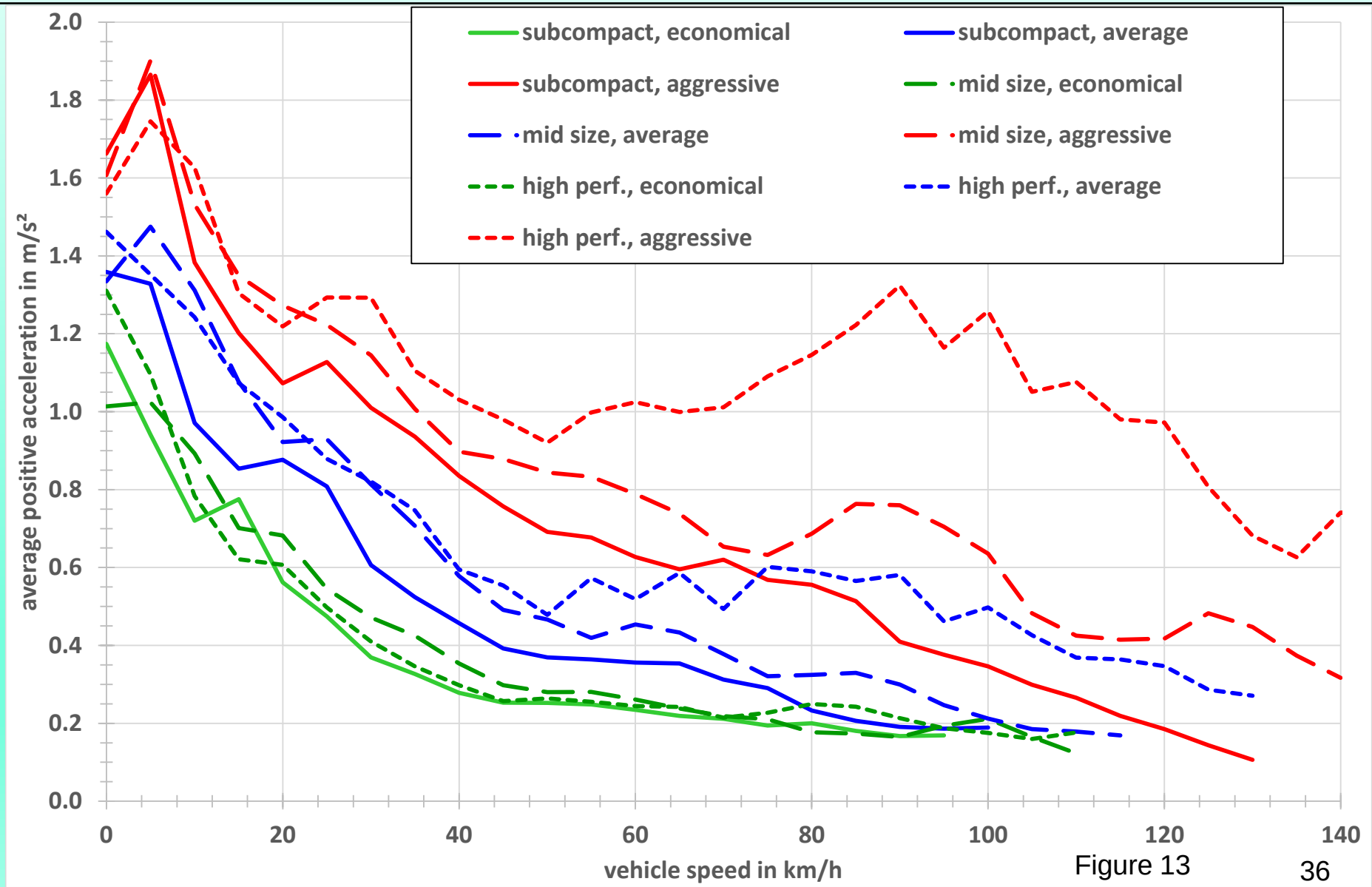


Figure 13

a-v distribution, subcompact ecological

subcompact, economical driving behaviour

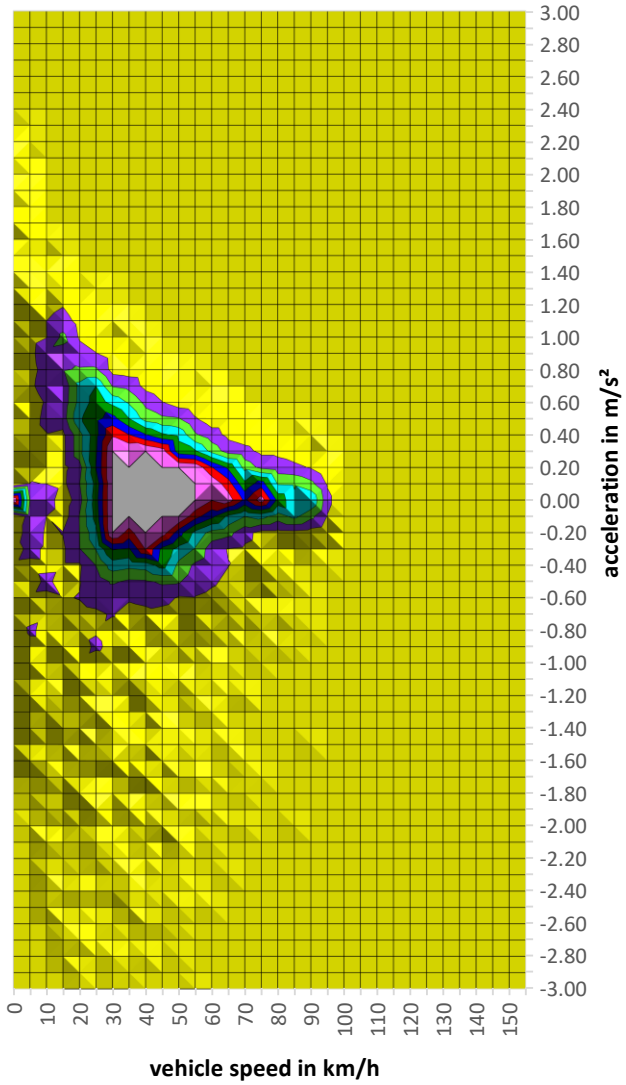


Figure 14a

a-v distribution, subcompact average

subcompact, average driving behaviour

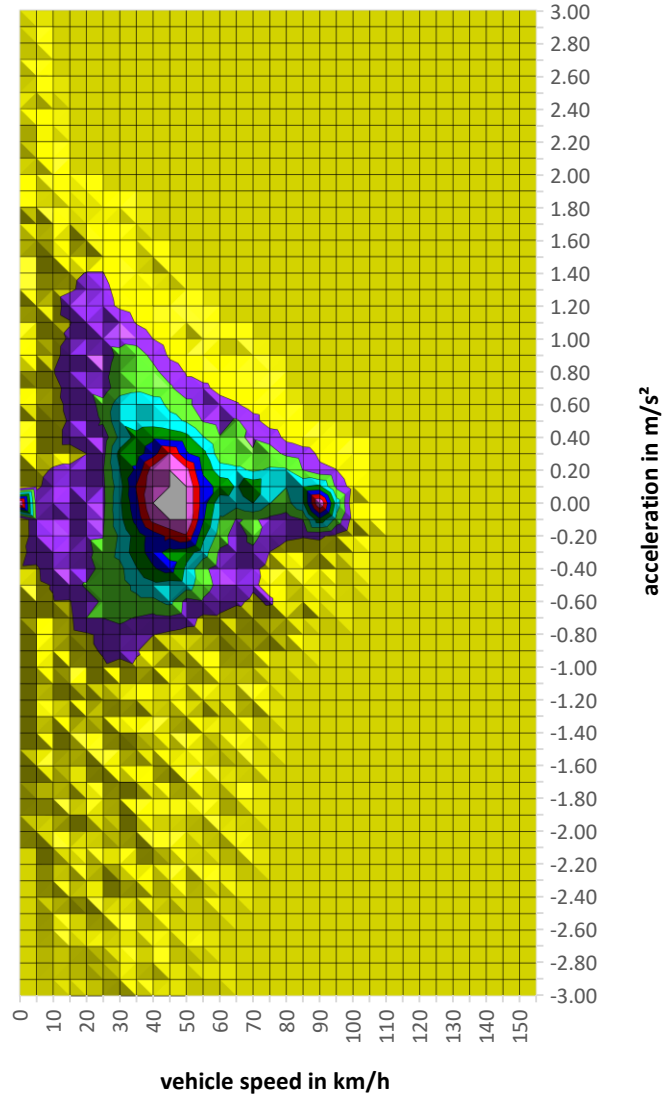


Figure 14b

a-v distribution, subcompact aggressive

subcompact, aggressive driving behaviour

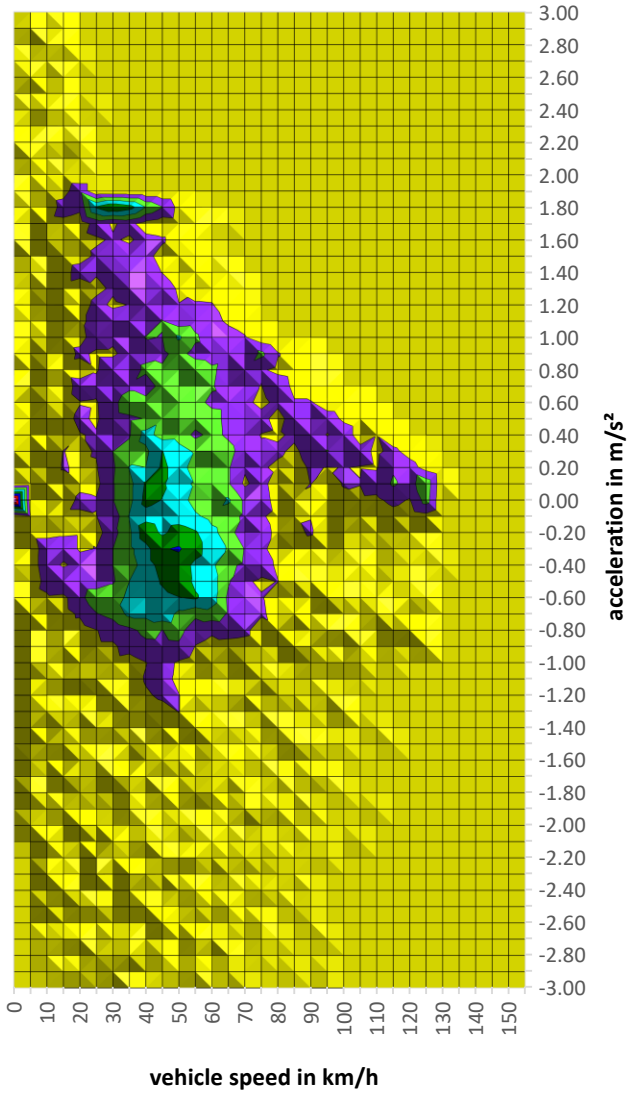


Figure 14c

a-v distribution, mid size ecological

mid size, economical driving behaviour

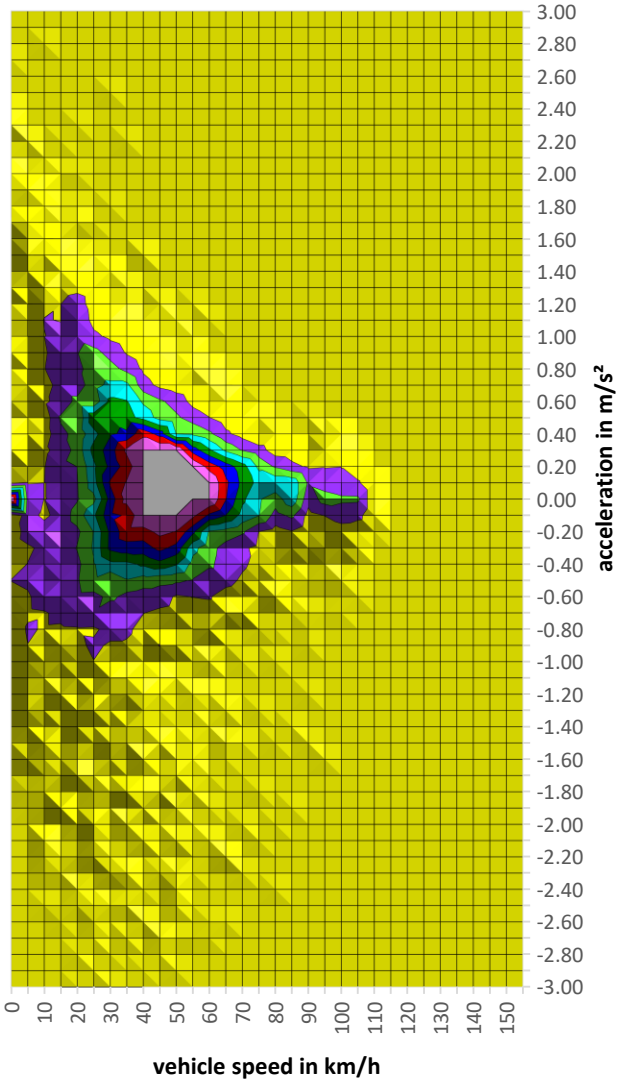


Figure 15a

a-v distribution, mid size average

mid size, average driving behaviour

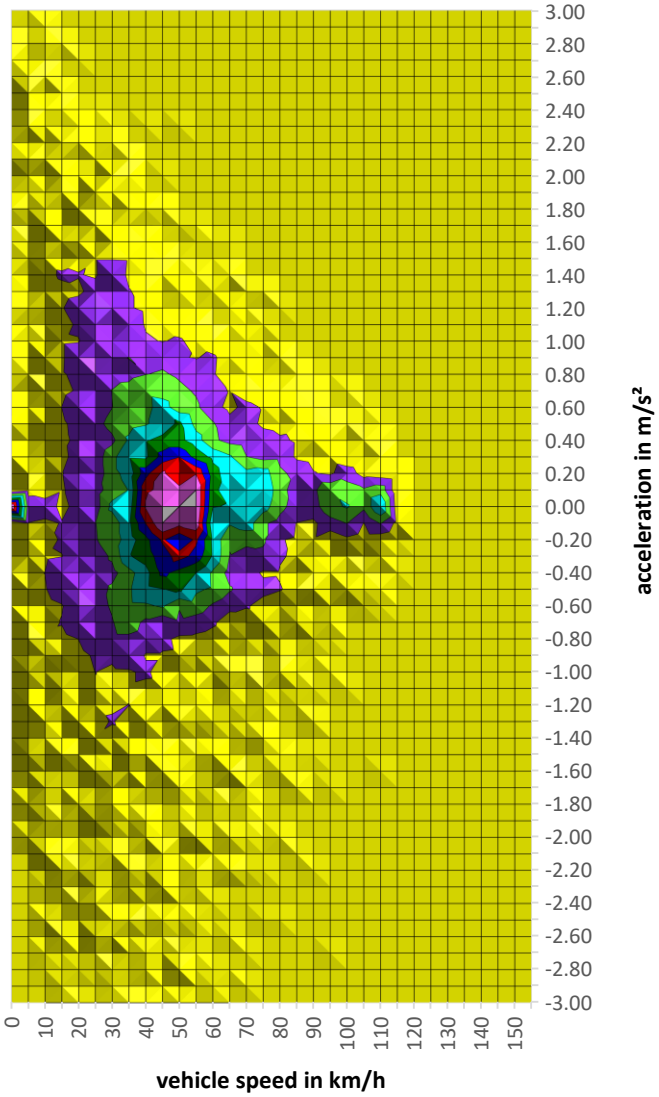


Figure 15b

a-v distribution, mid size aggressive

mid size, aggressive driving behaviour

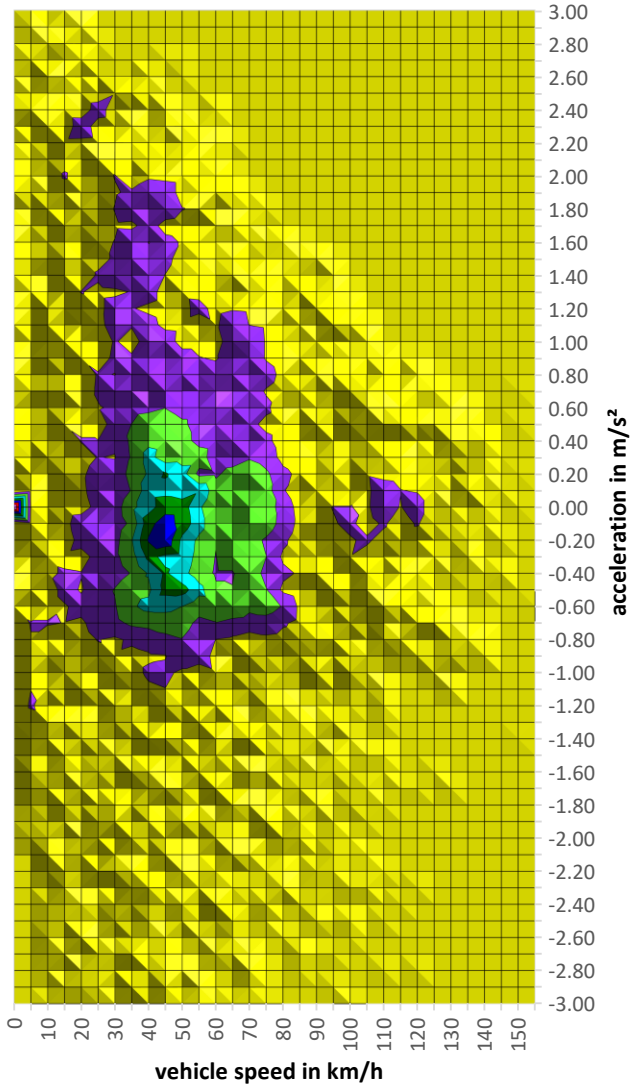


Figure 15c

a-v distribution, high performance ecological

high performance, economical driving behaviour

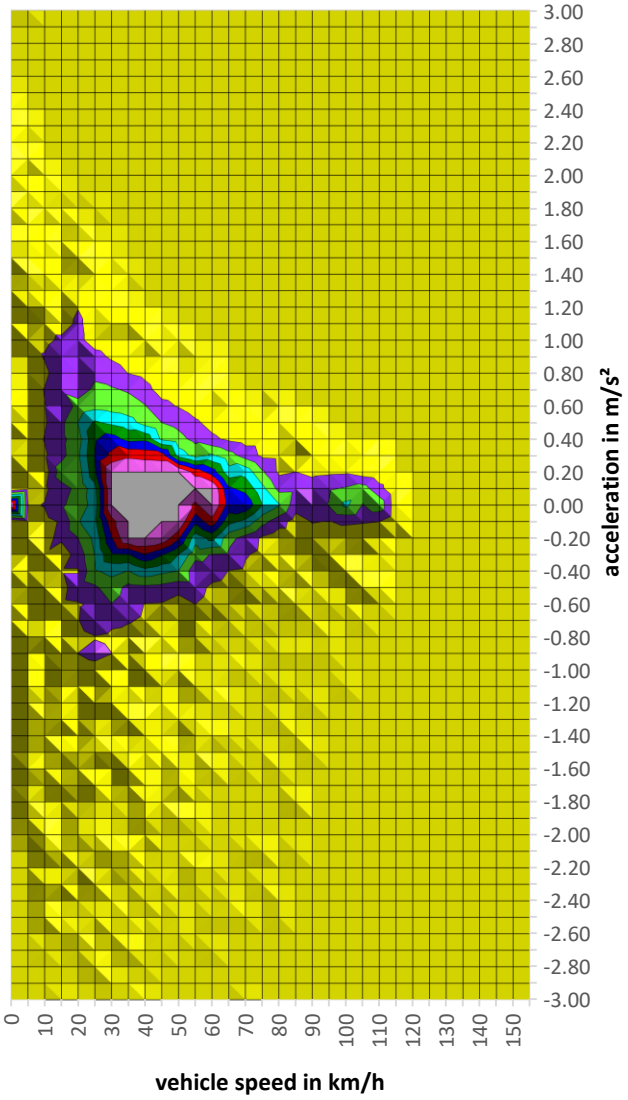


Figure 16a

a-v distribution, high performance average

high performance, average driving behaviour

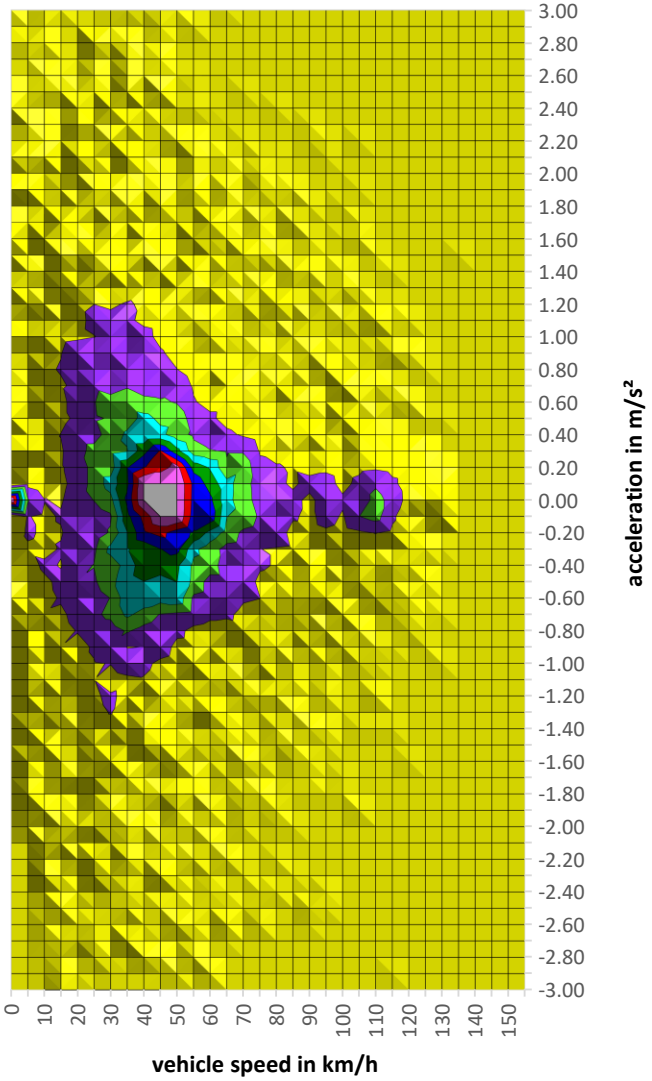


Figure 16b

a-v distribution, high performance aggressive

high performance, aggressive driving behaviour

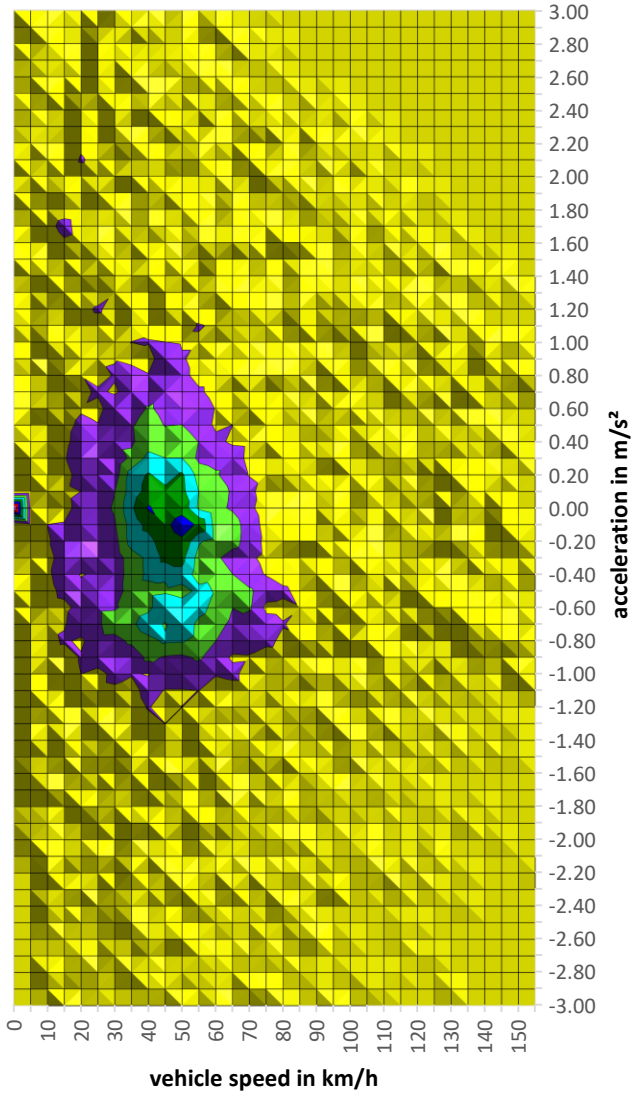


Figure 16c

Norm. engine speed distributions

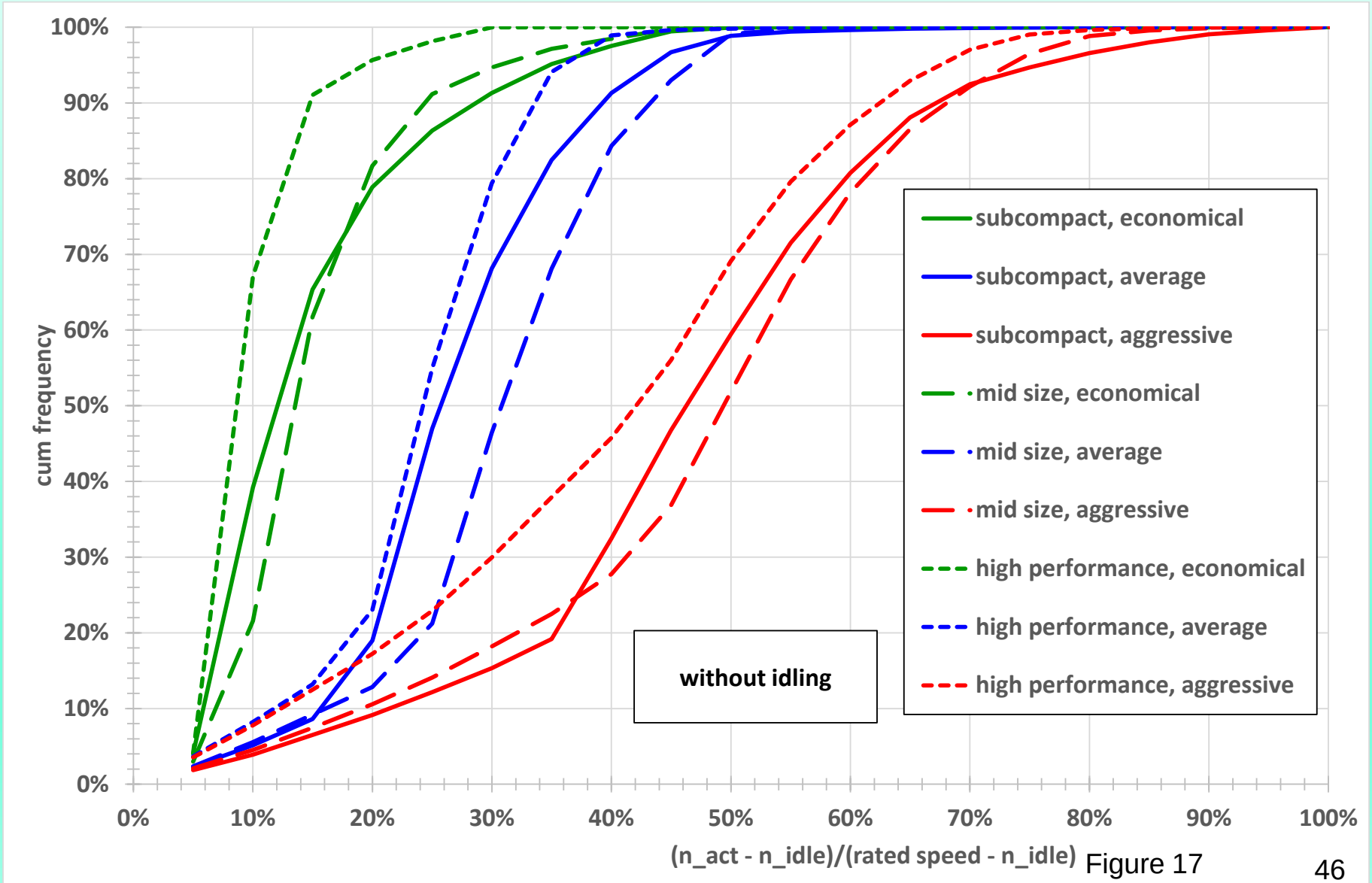
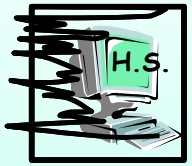


Figure 17

Norm. engine load distributions



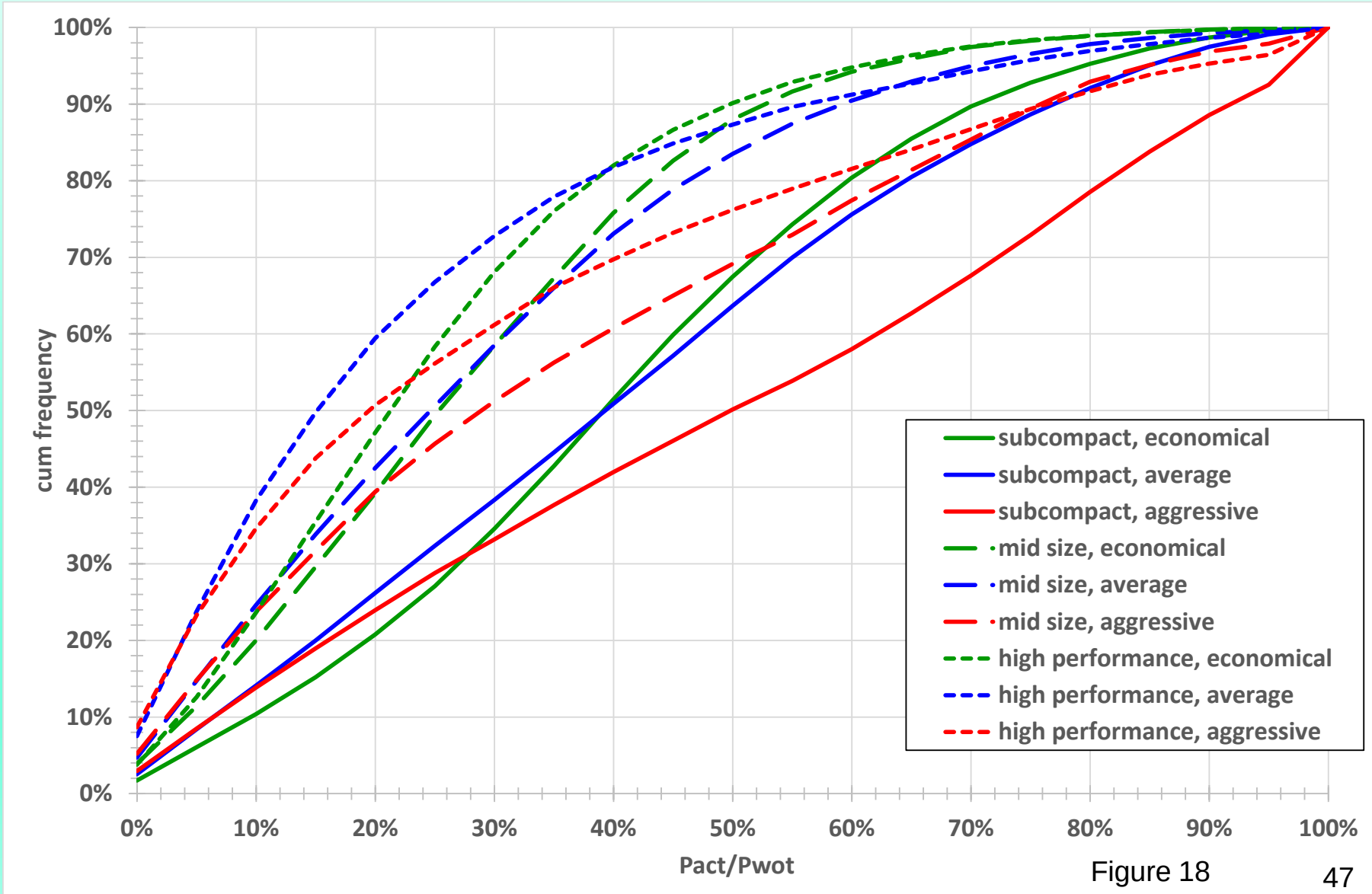


Figure 18

Norm. P/norm. n distribution, mid size ecological

mid size, economical driving behaviour

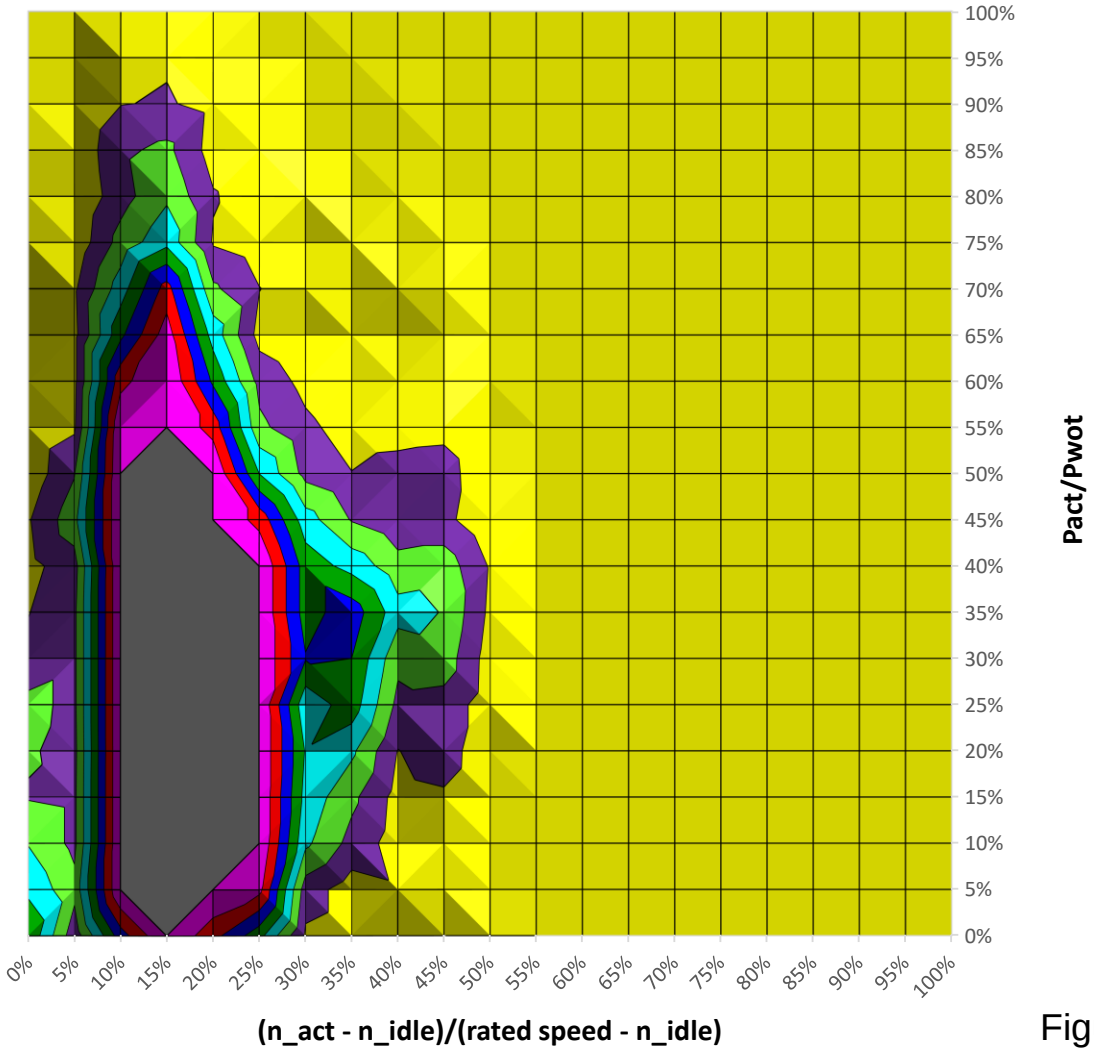


Figure 19a

Norm. P/norm. n distribution, mid size average

mid size, average driving behaviour

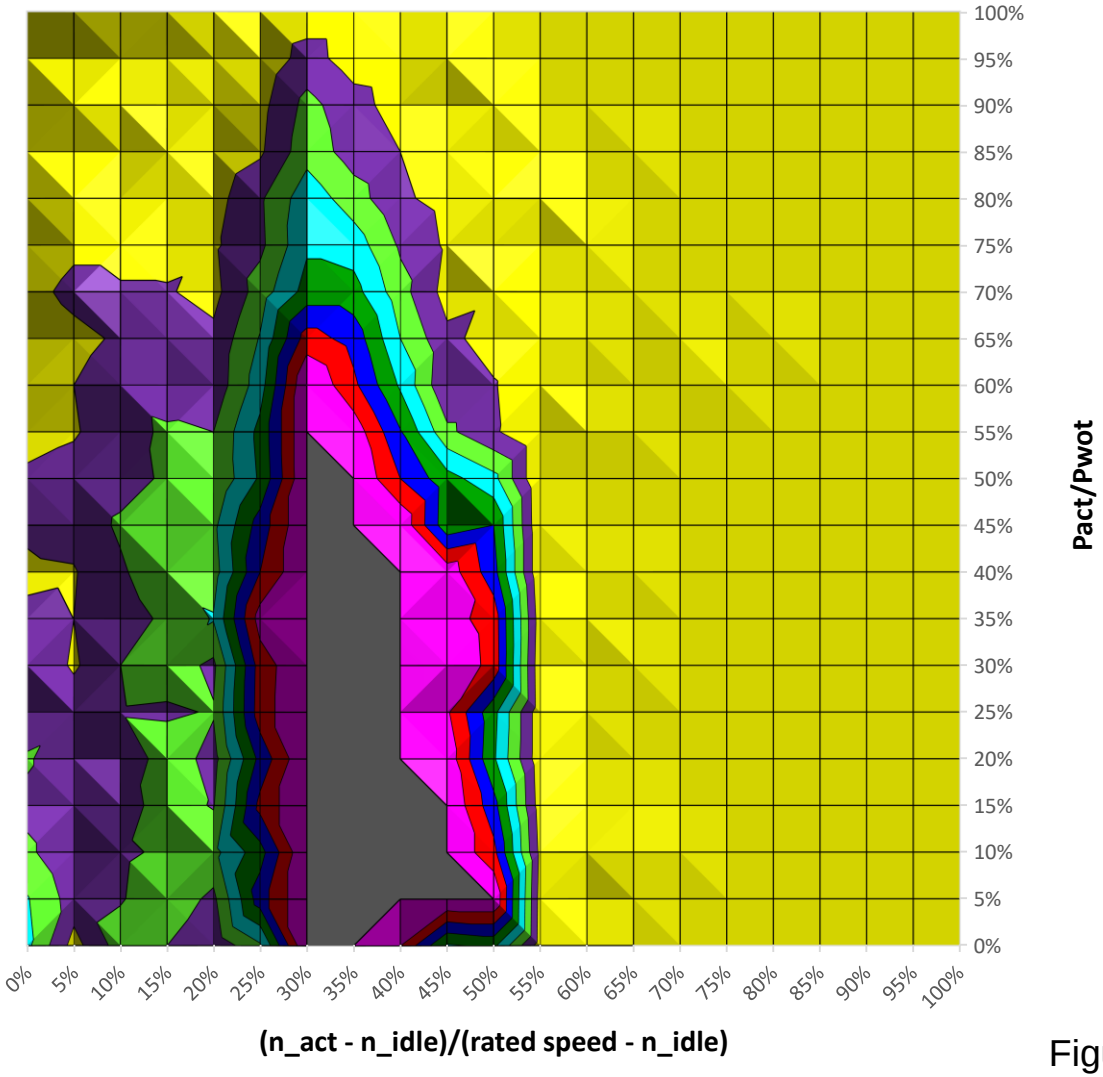


Figure 19b

Norm. P/norm. n distribution, mid size aggressive

mid size, aggressive driving behaviour

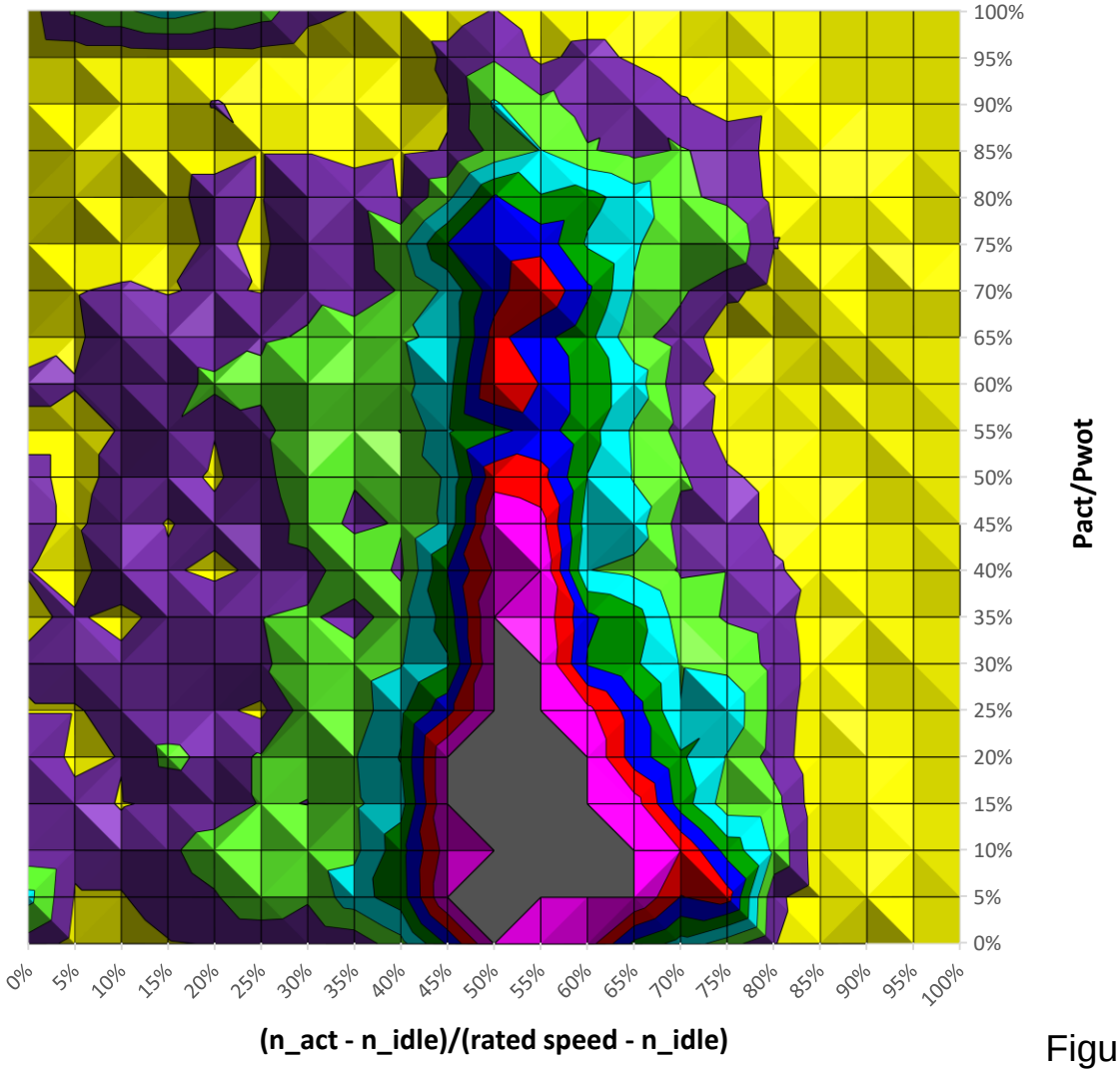


Figure 19c

Sound emission distributions, subcompact car

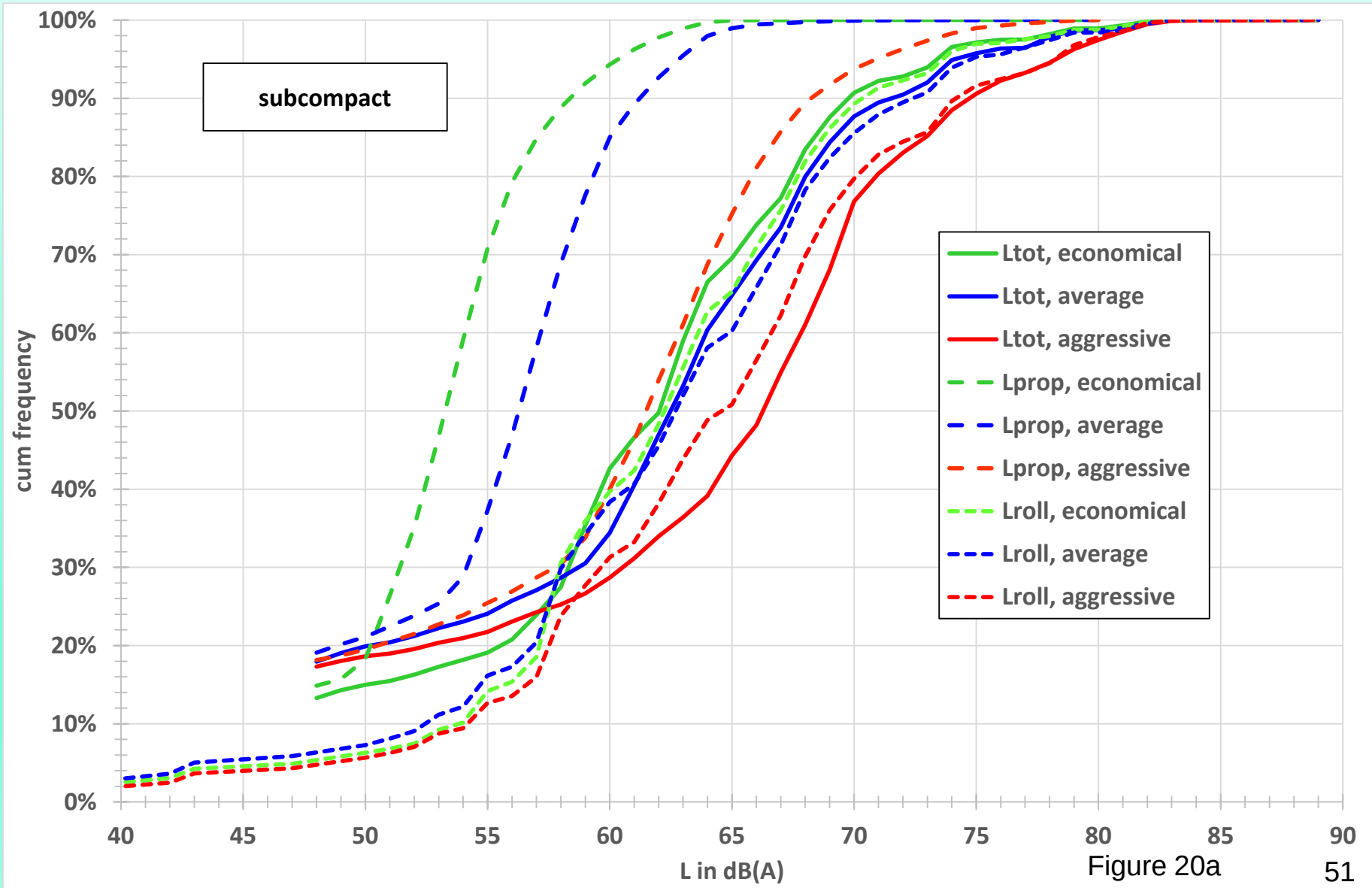


Figure 20a

Sound emission distributions, mid size car

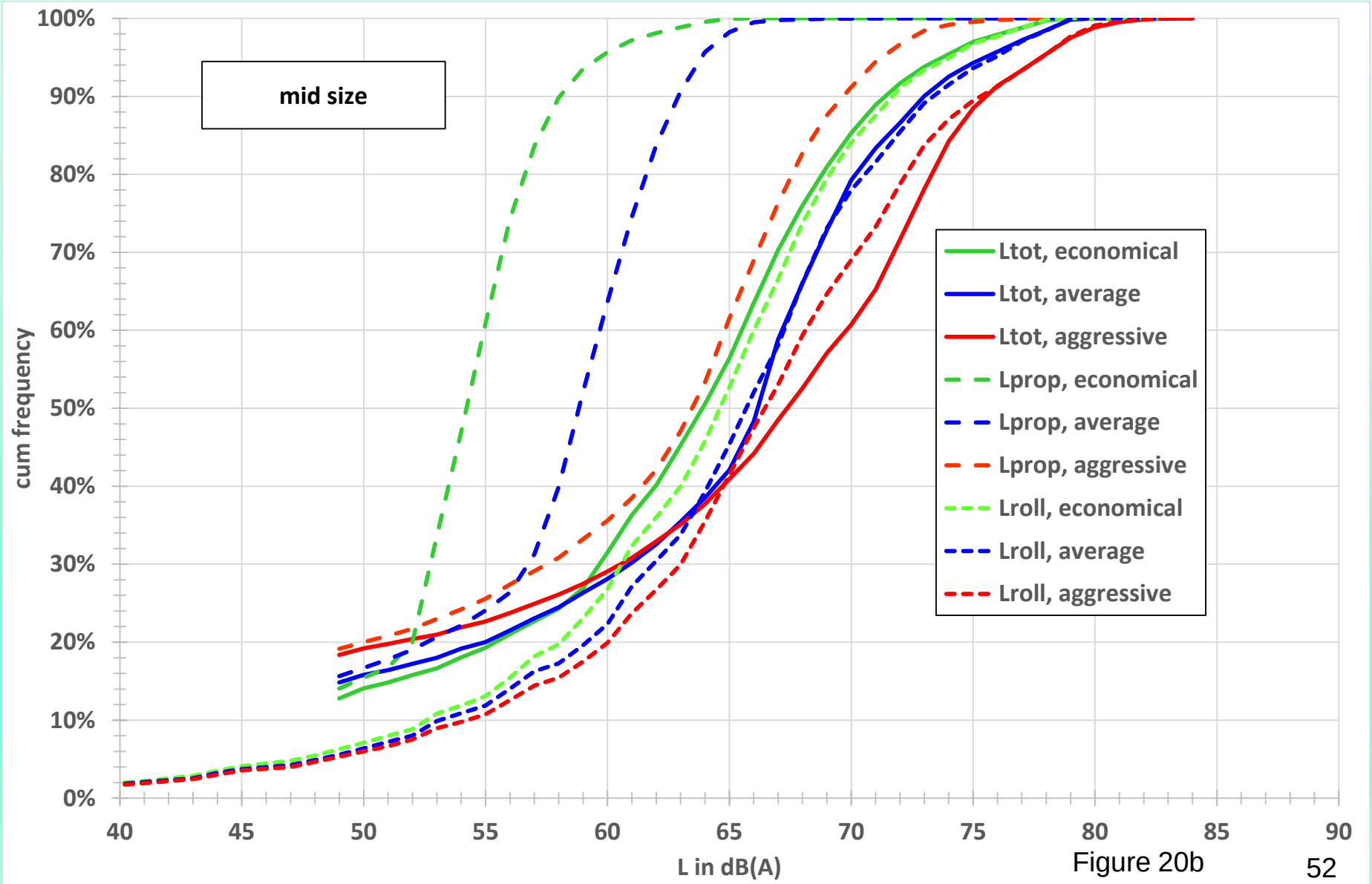


Figure 20b

Sound emission distributions, high performance car

high performance

cum frequency

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

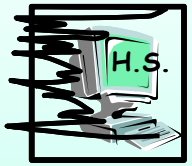
40 45 50 55 60 65 70 75 80 85 90

L in dB(A)

Ltot, economical
Ltot, average
Ltot, aggressive
Lprop, economical
Lprop, average
Lprop, aggressive
Lroll, economical
Lroll, average
Lroll, aggressive

Figure 20c

Total sound emission distributions, comparison



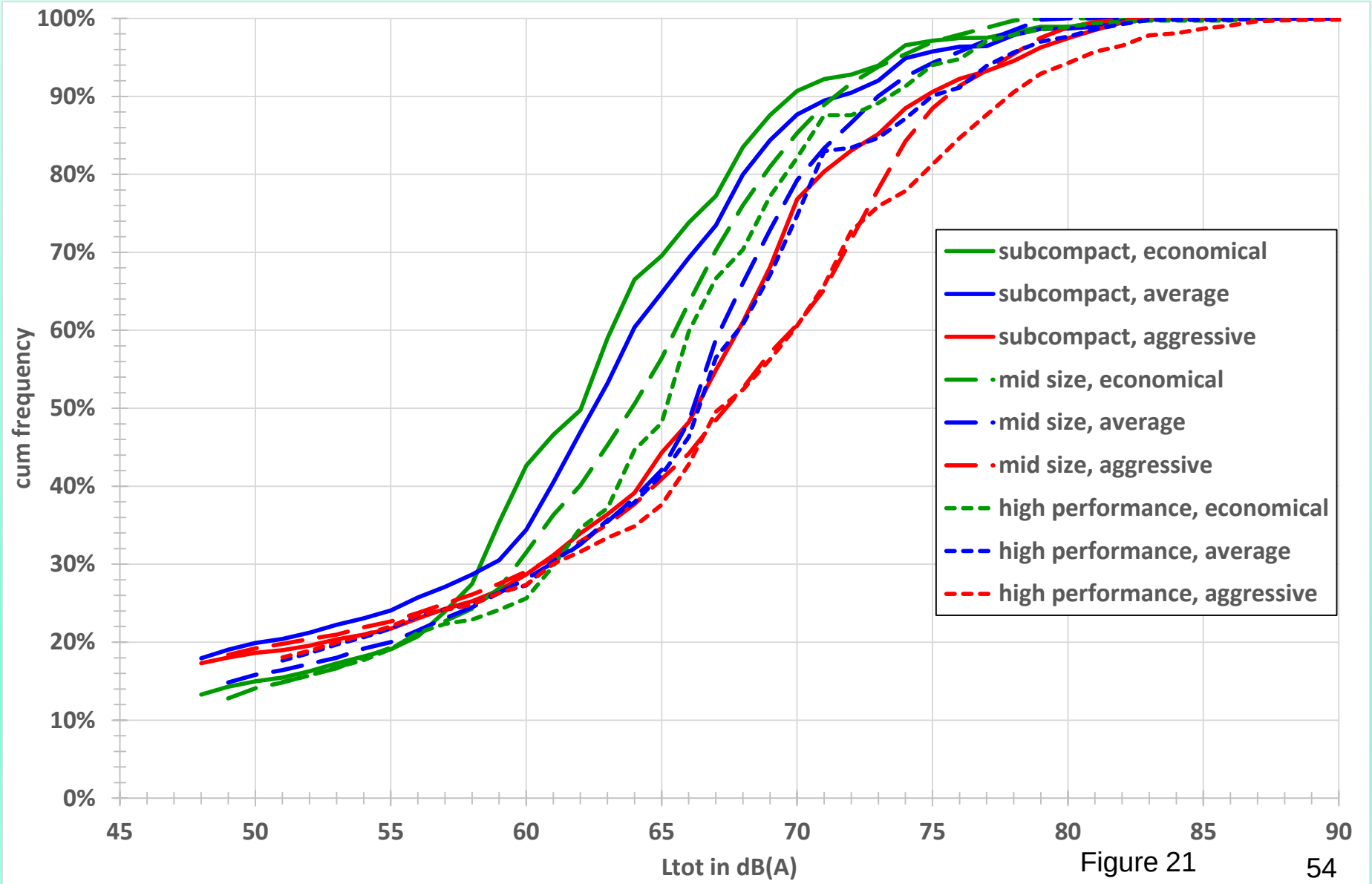


Figure 21

Average sound emission versus vehicle speed

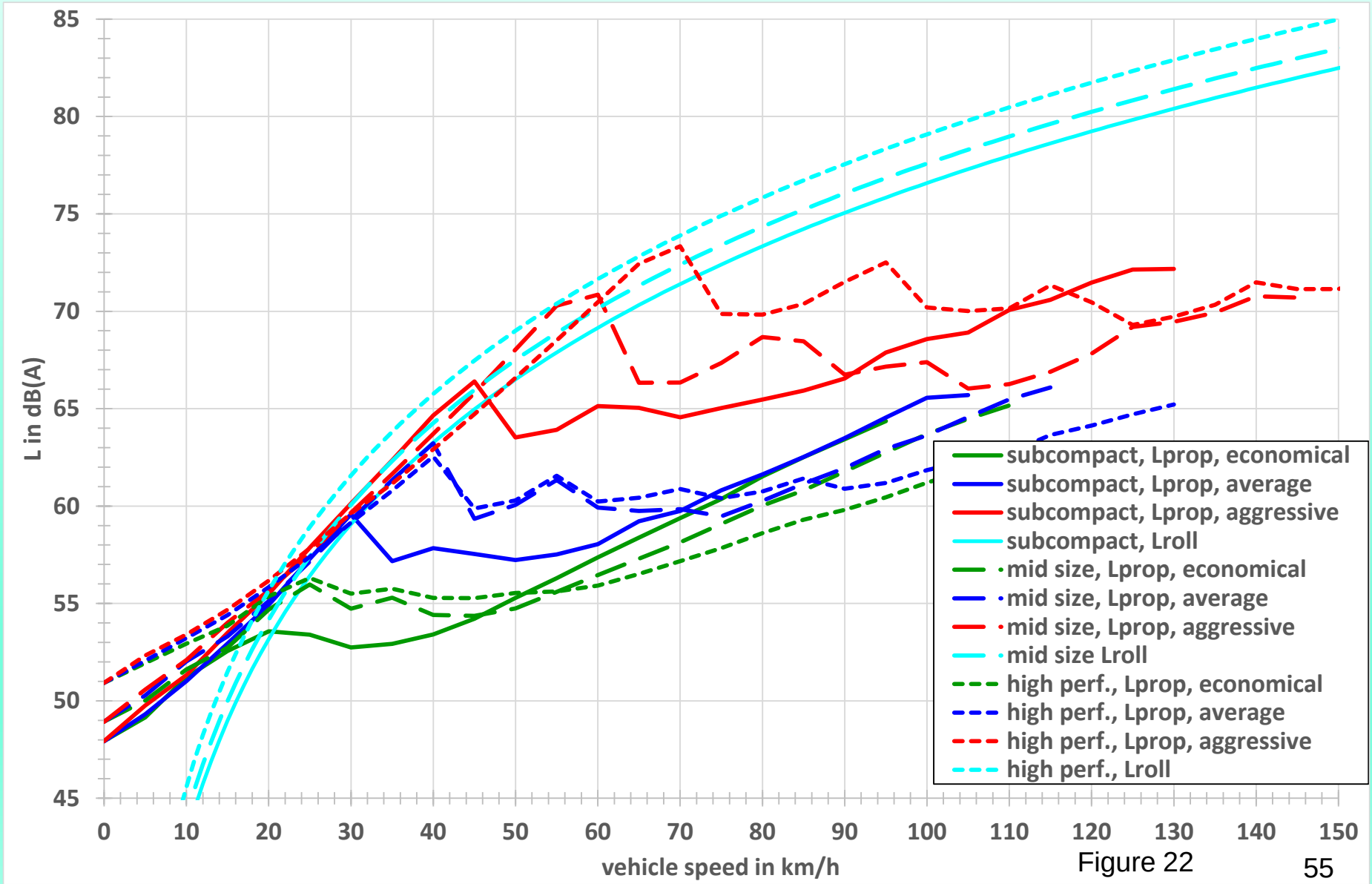


Figure 22

a-v matrix of sound emission, mid size car, ecological driving behaviour

mid size, economical driving behaviour

Ltot in dB(A)

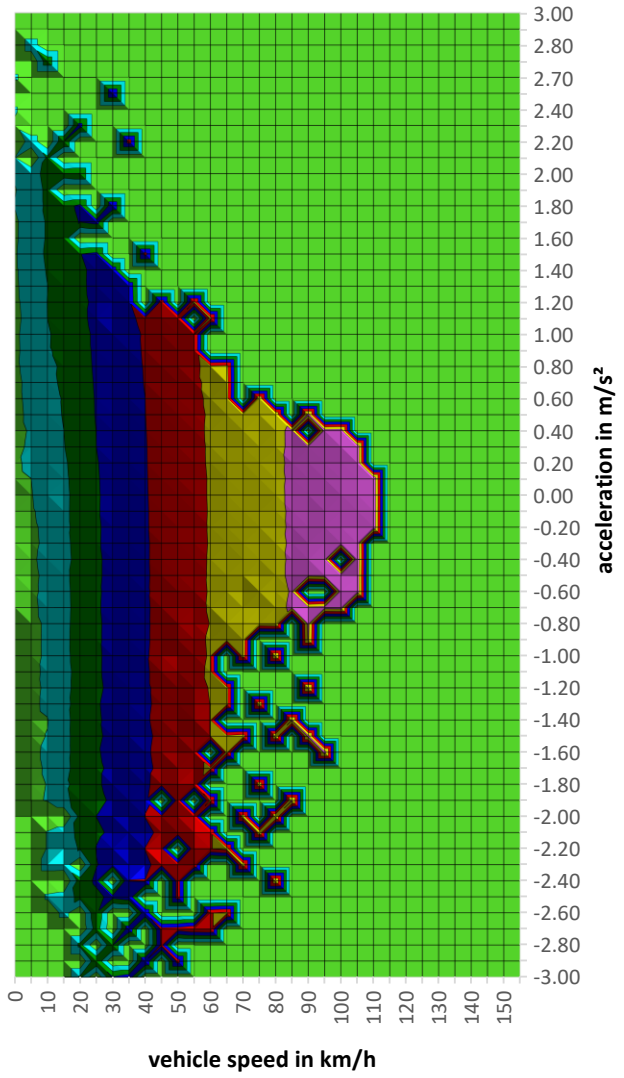


Figure 23a

a-v matrix of sound emission, mid size car, average driving behaviour

mid size, average driving behaviour

Ltot in dB(A)

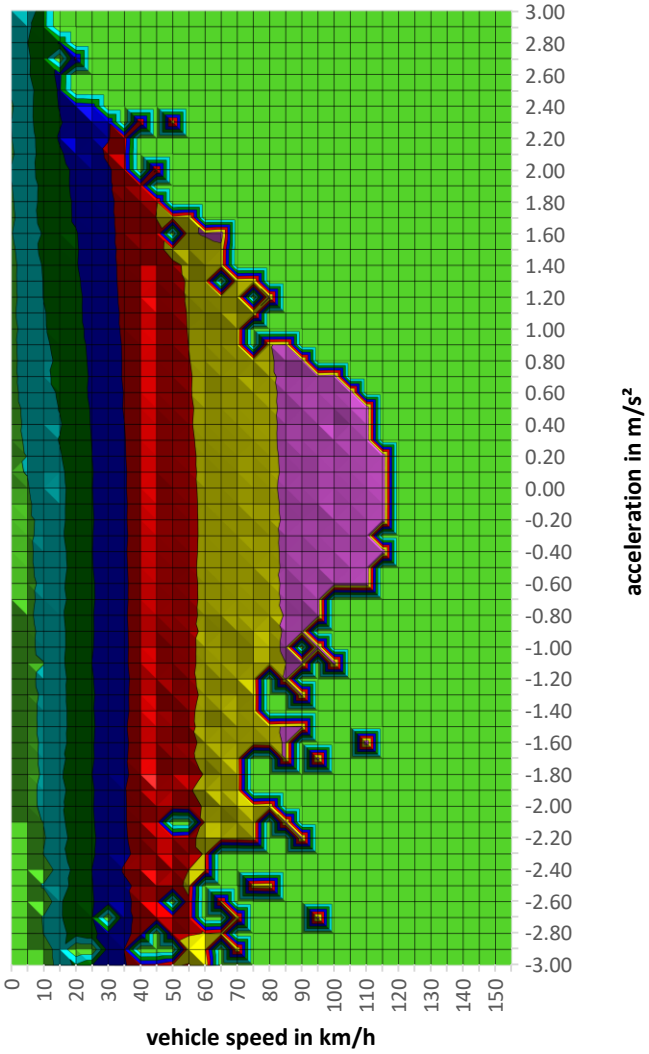


Figure 23b

a-v matrix of sound emission, mid size car, aggressive driving behaviour

mid size, aggressive driving behaviour

Ltot in dB(A)

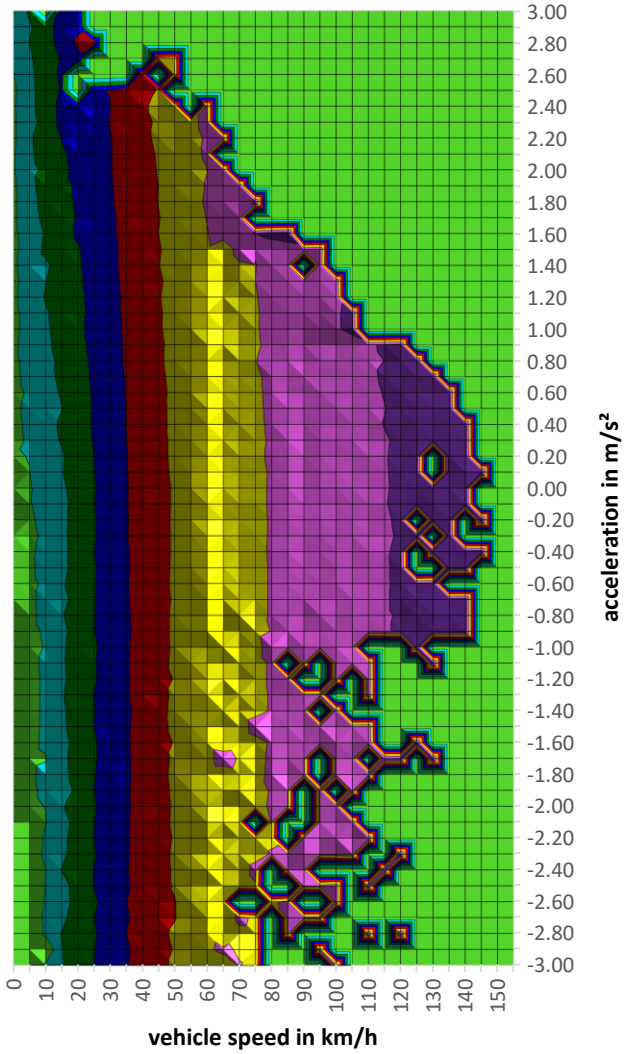


Figure 23c

Average sound emission versus vehicle speed

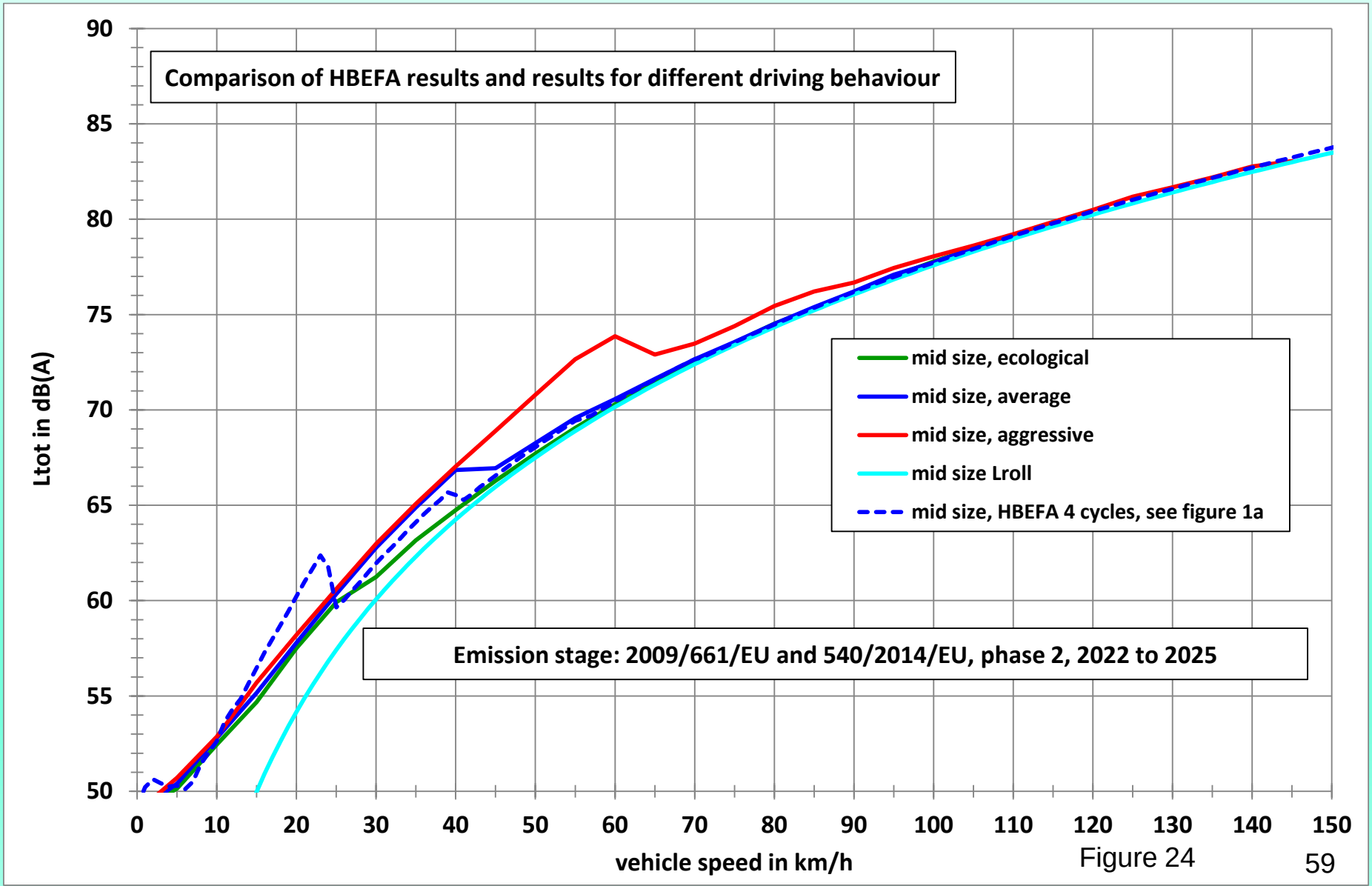


Figure 24

Comparison of average total sound emission

vehicle	ecological	average	aggressive	range
subcompact, Petrol	66.9	68.2	71.4	**4.5**
subcompact, Petrol	67.3	68.8	71.1	**3.8**
compact, Diesel	68.4	69.7	72.6	**4.3**
mid size, Petrol	67.5	68.6	70.6	**3.2**
mid size, Petrol	68.0	69.6	71.9	**3.9**
sports car, Petrol	70.2	72.3	74.2	**4.0**
high performance, Petrol	70.1	72.2	75.1	**5.0**
N1, Diesel	69.9	71.1	73.2	**3.3**
SUV, Diesel	69.1	69.9	73.4	**4.4**
max	**70.2**	**72.3**	**75.1**	
min	**66.9**	**68.2**	**70.6**	
range	**3.2**	**4.1**	**4.5**	

Table 2

Conclusions for different driving behaviour

- The results of the application of the Rotranomo model on the dataset with different driving behaviour are summarized in Table 2.
- The differences between the vehicles (range) increase from ecological to aggressive driving behaviour from 3.2 to 4.5 dB(A).
- But the difference between aggressive and ecological driving behaviour are slightly higher and can reach 5 dB(A).
- Sports and high performance cars are driven with higher overall sound emission than the other subcategories while subcompact cars are the quietest.

Conclusions for different driving behaviour

- **Figure 22 shows that the contribution of tyre/road sound emission and propulsion sound emission to the overall sound emission is slightly dependent on the vehicle subcategory but much stronger influenced by the driving behaviour.**
- **For ecological driving behaviour the tyre/road sound emission starts to become dominant between 20 and 25 km/h, for average driving behaviour the speed range is 30 to 40 km/h and for aggressive driving behaviour it is 50 to 70 km/h.**

End

Thank you for your attention!