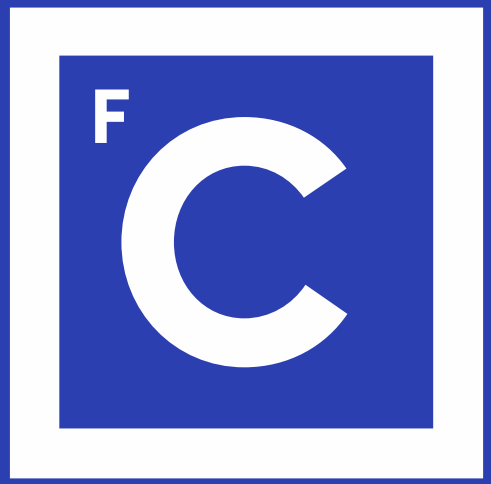


Ciências ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa

DISCIPLINA MIEA 2017

Sustainable Mobility

Emission factors….g/pkm

European Environment Agency

EEA Report | No 21/2016

EMEP/EEA air pollutant emission inventory guidebook 2016

Technical guidance to prepare national emission inventories

ISSN 1977-8449

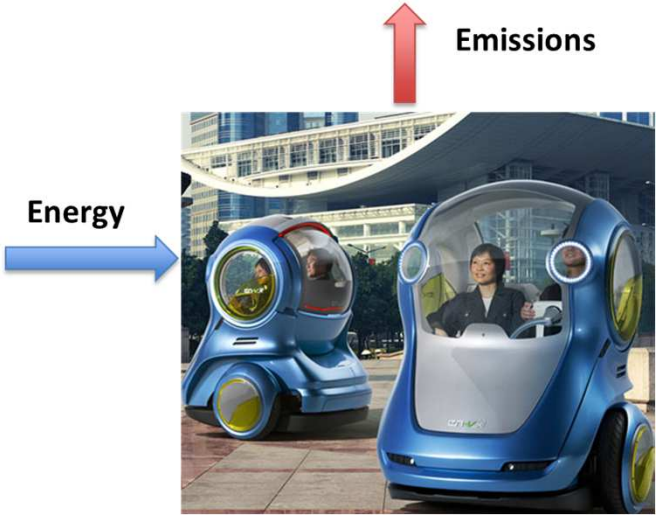
Regulations

EU Emission Standards for Passenger Cars (Category M_1*)

Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
		g/km					*#/km*
Compression Ignition (Diesel)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)	-
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08	-
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10	-
Euro 3	2000.01	0.64	-	0.56	0.50	0.05	-
Euro 4	2005.01	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009.09[b]	0.50	-	0.23	0.18	0.005[f]	-
Euro 5b	2011.09[c]	0.50	-	0.23	0.18	0.005[f]	6.0×10^{11}
Euro 6	2014.09	0.50	-	0.17	0.08	0.005[f]	6.0×10^{11}
Positive Ignition (Gasoline)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-	-
Euro 2	1996.01	2.2	-	0.5	-	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-	-
Euro 4	2005.01	1.0	0.10	-	0.08	-	-
Euro 5	2009.09[b]	1.0	0.10[d]	-	0.06	0.005[e,f]	-
Euro 6	2014.09	1.0	0.10[d]	-	0.06	0.005[e,f]	6.0×10^{11} [e,g]

* At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
a. until 1999.09.30 (after that date DI engines must meet the IDI limits)
b. 2011.01 for all models
c. 2013.01 for all models
d. and NMHC = 0.068 g/km
e. applicable only to vehicles using DI engines
f. 0.0045 g/km using the PMP measurement procedure
g. 6.0×10^{12} 1/km within first three years from Euro 6 effective dates

Road vehicles



P#6 Exercice

Estimate the energy consumption in MJ/pkm of a fleet of 5 motorized cars that travels roundtrip Lisbon –Porto (~300 km). Temp. 20^{o}C.
CO_2, NOx and PM2.5 in g/pkm.

a) Use refuelling info;

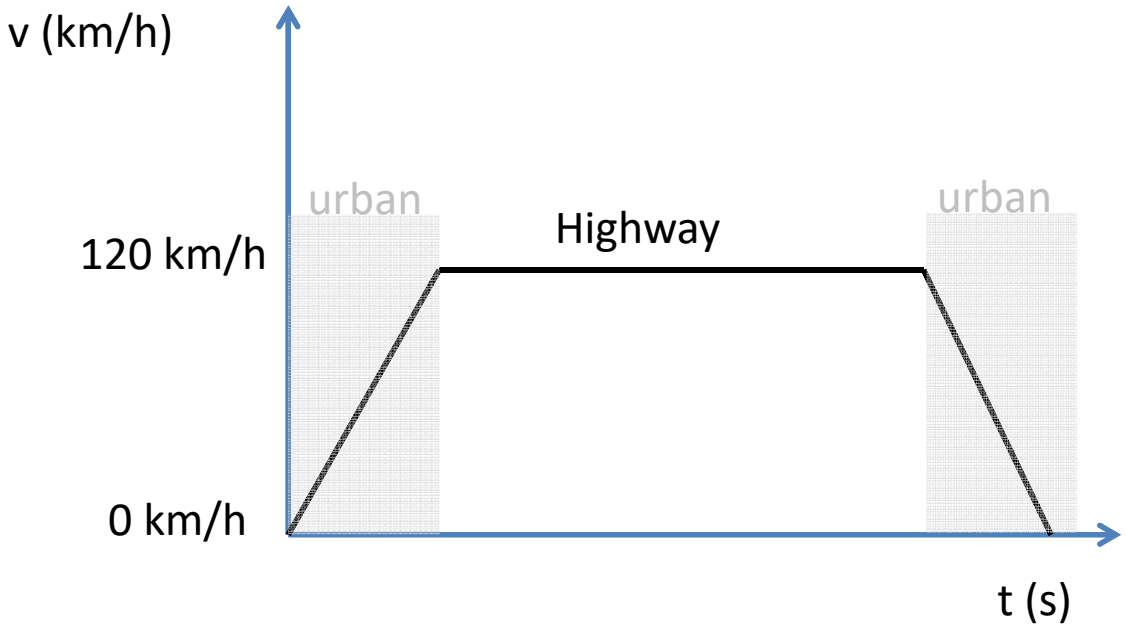
b) Use EEA Tier1/2/3;

c) Discuss results.

Exercise

	Gasoline (2x) Euro4	Diesel (2x) Euro3	HEV (1x) Euro4
Tank begin (l)	50	60	45
Tank end round-trip (l)	14	33	15
Speed	See driving cycle		
Curb weight	1200	1500	1400
Passengers	1	1	1
CD*AF (m2)	0.6	0.6	0.4
t (s) 0-100km/h	10.2	10.3	10
Engine efficiency	25	30	35
Transmission efficiency	95	95	95
A/C	off	off	off
A/C (kW)	2	2	2

Exercise



Driving cycle

Exercise

European Environment Agency

TIER 1 ?

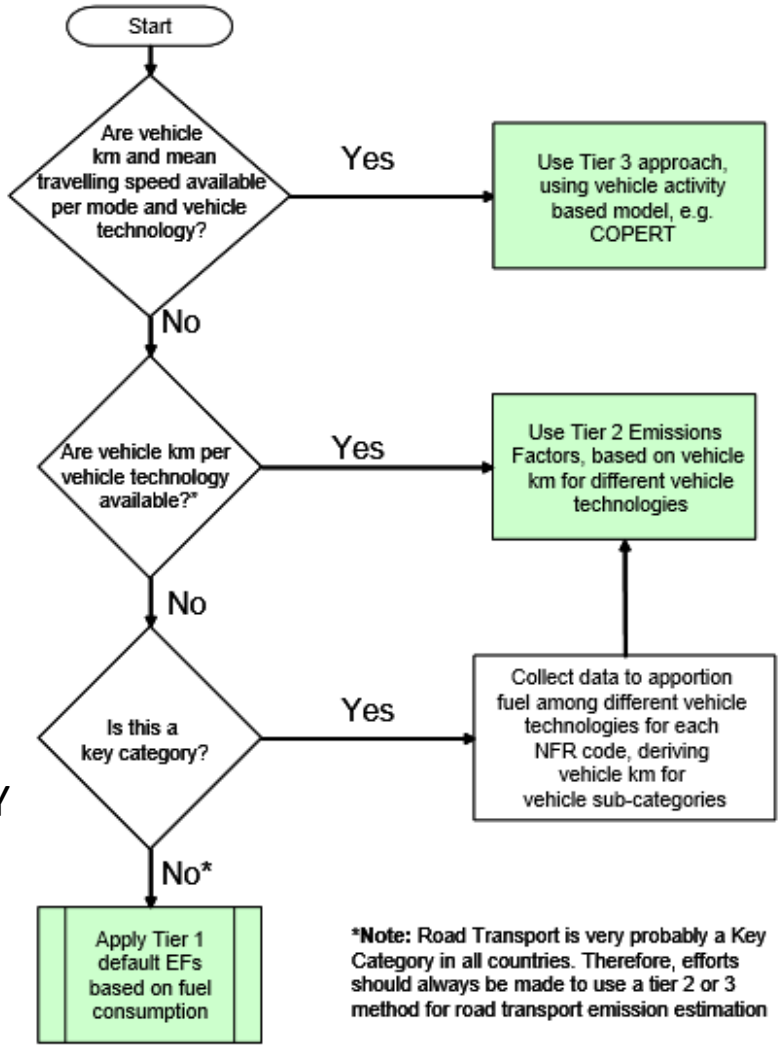
TIER 2 ?

TIER 3 ?

ETOTAL = EURBAN + ERURAL + EHIGHWAY

ETOTAL = EHOT + ECOLD

Figure 3-1 Decision tree for exhaust emissions from road transport



***Note:** Road Transport is very probably a Key Category in all countries. Therefore, efforts should always be made to use a tier 2 or 3 method for road transport emission estimation

Exercise

European Environment Agency

TIER 1 ?

EF = Emission Factor (g/km) = f(fuel consumption)

Exercise

European Environment Agency

TIER 2 ?

EF = Emission Factor (g/km) ≠ f(fuel consumption)

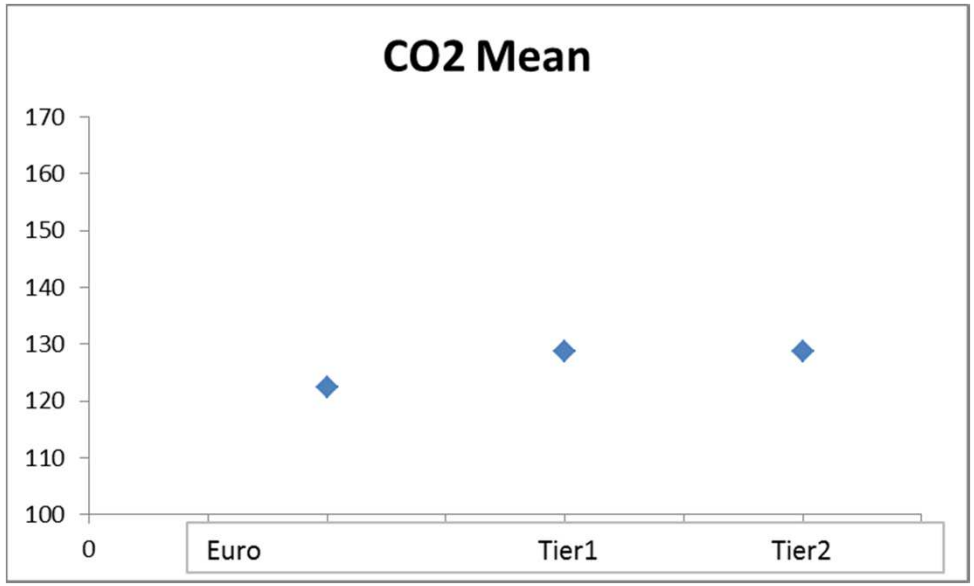
EF = Emission Factor (g/km) = f(vehicle category & standard)

Exercise

European Environment Agency

Euro/TIER 1/TIER 2 ?

g/pkm

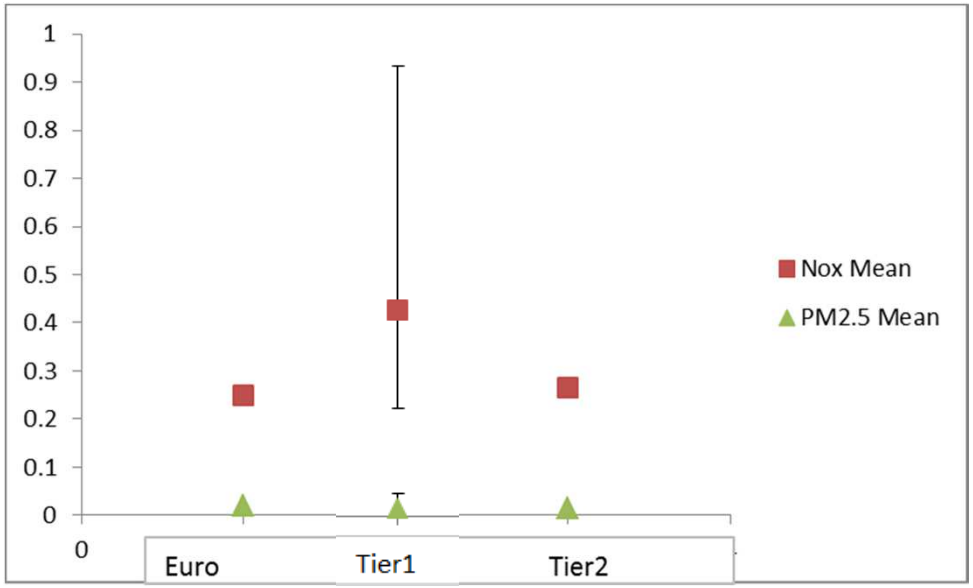


Exercise

European Environment Agency

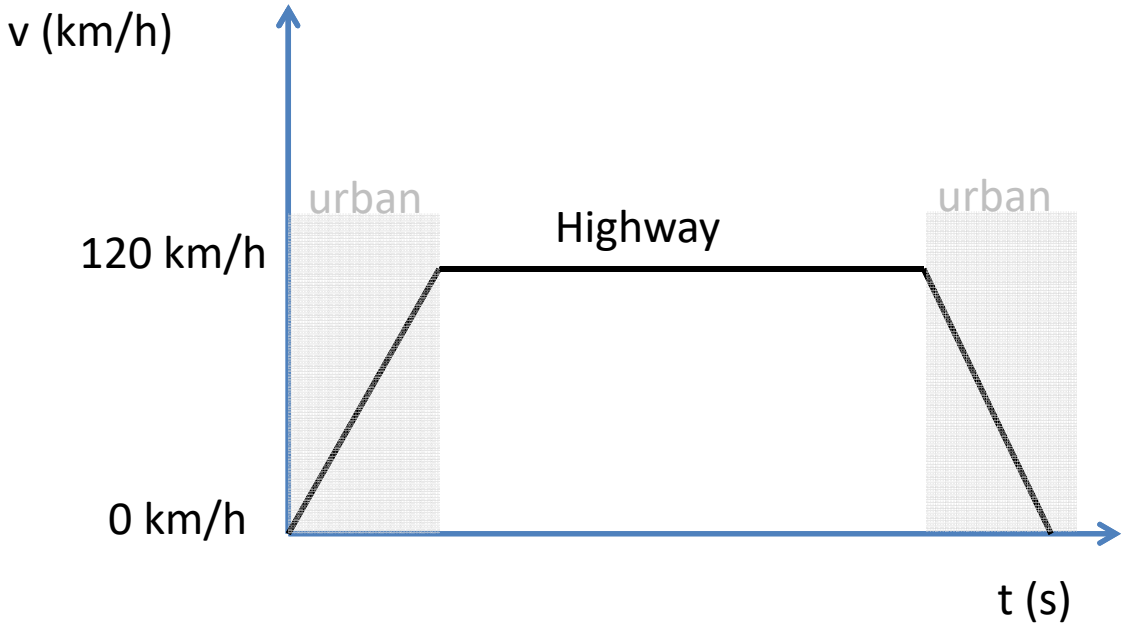
Euro/TIER 1/TIER 2 ?

g/pkm



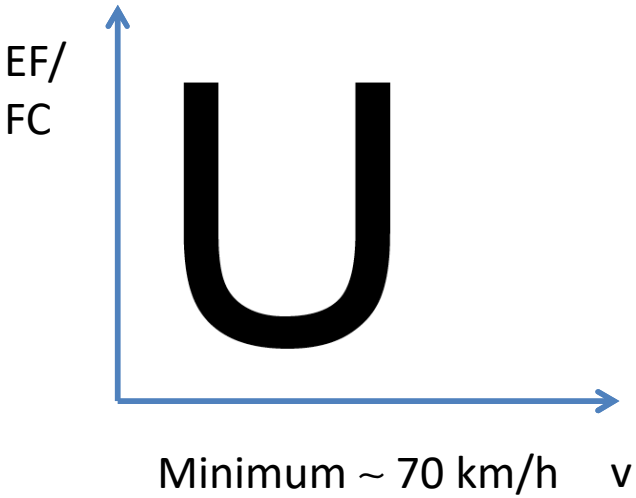
Exercise

Without refueling info? With GPS info….



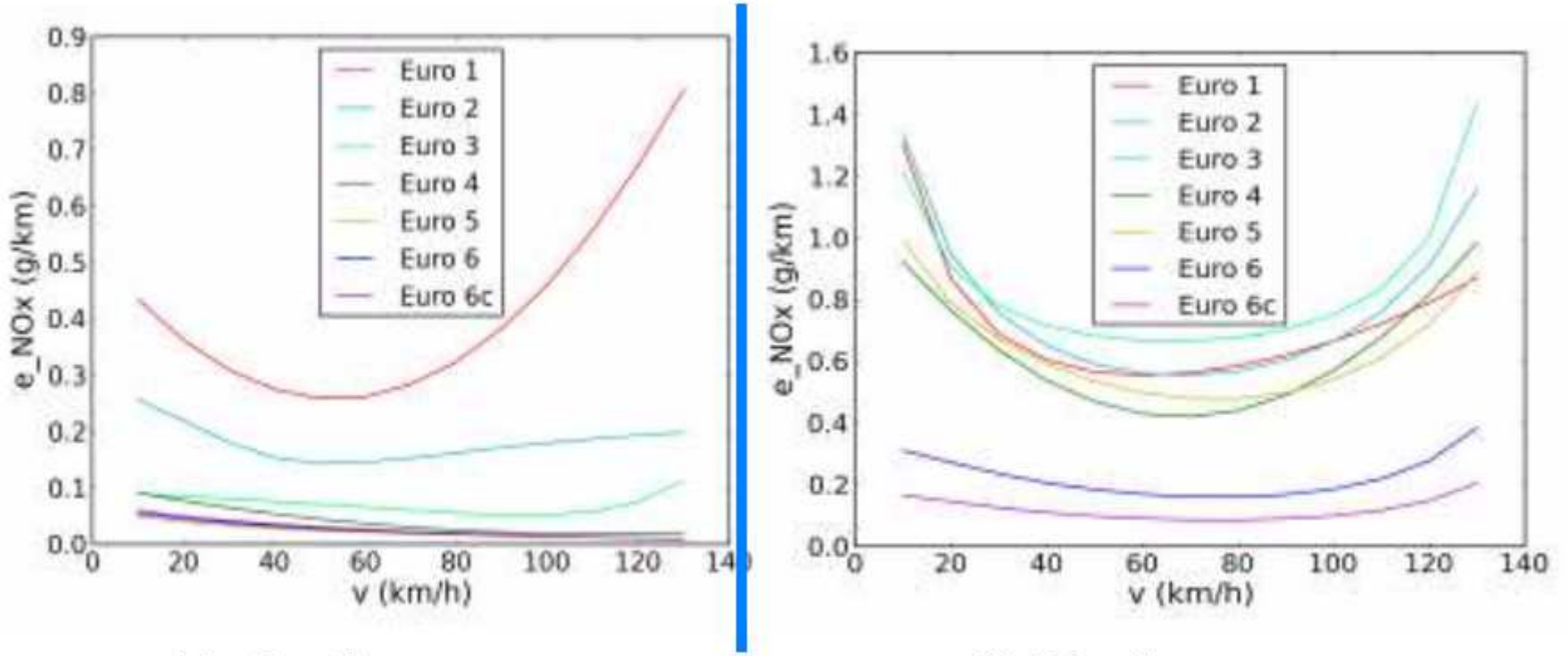
Driving cycle

Exercise



EF = Emission Factor (g/km) = f(vehicle category & standard, **average speed**, ambient temperature, A/C, Road slope, load)

Exercise



(a) Gasolinepassenger car

(b) Diesel passenger car

Figure 14: Sensitivity of hot emission factor of passenger cars for NO_x to the average speed.

Exercise

ltrip average trip length [km] Europe 12.4 km

Ta ^{o}C

Table 8-8: Cold mileage percentage β

Calculations based on	β-parameter (Beta parameter)
Estimated l_{trip}	$0.6474 - 0.02545 \times l_{trip} - (0.00974 - 0.000385 \times l_{trip}) \times t_a$

Exercise

ltrip =12.4 km

Ta = 20 ^{o}C

2.8 km

Exercise

Vaverage urban		**Vaverage highway**			km/h
13.88889		120			

Exercise

$$FChot\ (g/km) = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2)$$

Table 8-9: Values for eq.(21) to calculate emissions from Euro 1 and later gasoline passenger cars

Pollutant	Emission Standard	Engine capacity	Speed Range (km/h)	R^2	a	b	c	d	e
FC	Euro 1	<1.4	10-130	0.99	1.91E+02	1.29E-01	1.17E+00	-7.23E-04	
		1.4-2.0	10-130	0.98	1.99E+02	8.92E-02	3.46E-01	-5.38E-04	
		>2.0	10-130	0.93	2.30E+02	6.94E-02	-4.26E-02	-4.46E-04	
	Euro 2	<1.4	10-130	0.99	2.08E+02	1.07E-01	-5.65E-01	-5.00E-04	1.43E-02
		1.4-2.0	10-130	0.98	3.47E+02	2.17E-01	2.73E+00	-9.11E-04	4.28E-03
		>2.0	10-130	0.98	1.54E+03	8.69E-01	1.91E+01	-3.63E-03	
	Euro 3	<1.4	10-130	0.99	1.70E+02	9.28E-02	4.18E-01	-4.52E-04	4.99E-03
		1.4-2.0	10-130	0.99	2.17E+02	9.60E-02	2.53E-01	-4.21E-04	9.65E-03
		>2.0	10-130	0.99	2.53E+02	9.02E-02	5.02E-01	-4.69E-04	
	Euro 4	<1.4	10-130	0.95	1.36E+02	2.60E-02	-1.65E+00	2.28E-04	3.12E-02
		1.4-2.0	10-130	0.96	1.74E+02	6.85E-02	3.64E-01	-2.47E-04	8.74E-03
		>2.0	10-130	0.98	2.85E+02	7.28E-02	-1.37E-01	-4.16E-04	

Table 8-11: Over-emission ratios e^{COLD} / e^{HOT} for Euro 1 and later gasoline vehicles (V: speed in km/h, t_a: temperature in °C)

Case	Category	Speed [km/h]	Temp [°C]	$e^{COLD}/e^{HOT} = A \times V + B \times t_a + C$ A	B	C
FC	All Classes	-	-10 : 30	0	-0.009	1.47

Note: e^{COLD}/e^{HOT} should be replaced with unit when it is calculated less than unit within the temperature and speed application limits

Exercise

$$FChot\ (g/km) = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) + f/V$$

Table 8-15: Values for eq.(23) to calculate emissions from Euro 1 and later diesel passenger cars

Pollutant	Emission Standard	Engine capacity	Speed Range (km/h)	R^2	a	b	c	d	e	f
FC	Euro 1	<2.0	10-130	0.98	1.45E+02	6.73E-02	-1.88E-01	-3.17E-04	9.47E-03	
		>2.0	10-130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	
	Euro 2	<2.0	10-130	0.97	1.42E+02	4.98E-02	-6.51E-01	-1.69E-04	1.32E-02	
		>2.0	10-130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	
	Euro 3	<2.0	10-130	0.95	1.62E+02	1.23E-01	2.18E+00	-7.76E-04	-1.28E-02	
		>2.0	10-130	0.96	1.95E+02	7.19E-02	1.87E-01	-3.32E-04	9.99E-03	

Table 8-14: Over-emission ratios e^{COLD} / e^{HOT} for diesel passenger cars (temperature range -10°C to 30°C)

Pollutant	e^{COLD} / e^{HOT}
CO	$1.9 - 0.03\ t_a$
NO_x	$1.3 - 0.013\ t_a$
VOC	$3.1 - 0.09\ t_a$ (1)
PM	$3.1 - 0.1\ t_a$ (2)
Fuel Consumption	$1.34 - 0.008\ t_a$

(1) VOC: if $ta > 29°C$ then $e^{COLD} / e^{HOT} > 0.5$
(2) PM: if $ta > 26°C$ then $e^{COLD} / e^{HOT} > 0.5$

Exercise

$$EF = a + c \times V + e \times V^2$$

Table 8-23: Values for eq.(26) to calculate emissions from hybrid gasoline passenger cars

Pollutant	Emission Standard	Engine capacity	Speed Range (km/h)	R^2	a	c	e
FC		All capacities	10-130	1	1.94E+01	6.06E-02	7.54E-04

Exercise

ecold/ehot		
Gasoline	Diesel	HEV
1.29	1.18	1.29

		FCHOT urban		FCHOT highway			g/km
	Gasoline	Diesel	HEV	Gasoline	Diesel	HEV	
	146.6168	74.18335	20.38711	71.70013	52.18074	37.5296	
Fctotal	80.98687	37.48258	11.26125	21562.46	15664.36	11269.53	g

Fleet average ~ 2.29 MJ/pkm

Exercise

NOx and PM2.5?

$$EF = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2)$$

Euro 3	All >0.8 l		10–130	0.80	9.29E-02	-1.22E-02	-1.49E-03	3.97E-05	6.53E-06
Euro 4	All		10–130	0.71	1.06E-01		-1.58E-03		7.10E-06

Table 3-43: PM emission factors for Euro 1 to Euro 4 gasoline passenger cars

Pollutant	Emission standard	Fuel specs (EN590)	Urban [g/km]	Rural [g/km]	Highway [g/km]
PM	Euro 1 and 2	2000–2009	3.22E-03	1.84E-03	1.90E-03
	Euro 3 and 4	2000–2009	1.28E-03	8.36E-04	1.19E-03
	Euro 3 GDI	2000–2009	6.60E-03	2.96E-03	6.95E-03

Gasoline hot emissions g/km (V in km/h)

Exercise

i) Could you estimate NOx and PM2.5?

Tier 3 emissions factors

1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv

Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

Table 3-44: Over-emission ratios e^{COLD} / e^{HOT} for Euro 1 and later gasoline vehicles (*V*: speed in km/h, t_a: temperature in °C)

Case	Category	Speed [km/h]	Temp [°C]	$e^{COLD}/e^{HOT} = A \times V + B \times t_a + C$ A	B	C
CO	cc< 1.4 l	5– 25	-20 : 15	0.156	-0.155	3.519
		26–45	-20 : 15	0.538	-0.373	-6.24
		5–45	> 15	8.032E-02	-0.444	9.826
	1.4 l < cc < 2.0 l	5–25	-20 : 15	0.121	-0.146	3.766
		26–45	-20 : 15	0.299	-0.286	-0.58
		5–45	> 15	5.03E-02	-0.363	8.604
	cc> 2.0 l	5–25	-20 : 15	7.82E-02	-0.105	3.116
		26–45	-20 : 15	0.193	-0.194	0.305
		5–45	> 15	3.21E-02	-0.252	6.332
NOx	cc< 1.4 l	5–25	> -20	4.61E-02	7.38E-03	0.755
		26–45	> -20	5.13E-02	2.34E-02	0.616
	1.4 l < cc < 2.0 l	5–25	> -20	4.58E-02	7.47E-03	0.764
		26–45	> -20	4.84E-02	2.28E-02	0.685
	cc>2.0 l	5–25	> -20	3.43E-02	5.66E-03	0.827
		26–45	> -20	3.75E-02	1.72E-02	0.728

Gasoline cold emissions

Exercise

$$EF = (a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) + f/V$$

Tier 3 emissions factors

Table 3-48: Values for equations (26), (27), (30) and (31) to calculate emissions and fuel consumption from Euro 1 and later diesel passenger cars

Pollutant or FC	Emission standard	Engine capacity	Eq. Nb.	Speed range (km/h)	R^2	a	b	c	d	e	f
NO_x	Euro 1	All>1.4 l	(30)	10–130	0.96	3.10E+00	1.41E-01	-6.18E-03	-5.03E-04	4.22E-04	
	Euro 2	All>1.4 l		10–130	0.94	2.40E+00	7.67E-02	-1.16E-02	-5.00E-04	1.20E-04	
	Euro 3	All>1.4 l		10–130	0.92	2.82E+00	1.98E-01	6.69E-02	-1.43E-03	-4.63E-04	
	Euro 4	All		10–130		1.11E+00		-2.02E-02		1.48E-04	
	Euro 5	All		10–130	0.923	9.46E-01	4.26E-03	-1.14E-02	-5.15E-05	6.67E-05	1.92E+00
PM	Euro 1	All>1.4 l	(30)	10–130	0.70	1.14E-01		-2.33E-03		2.26E-05	
	Euro 2	All>1.4 l		10–130	0.71	8.66E-02		-1.42E-03		1.06E-05	
	Euro 3	All>1.4 l		10–130	0.81	5.15E-02		-8.80E-04		8.12E-06	
	Euro 4	All		10–130		4.50E-02		-5.39E-04		3.48E-06	
	Euro 5	All	(31)	10-130	0.984	1.17E-03	1.06E+01	-6.48E+00	5.67E-01	1.23E-02	0.00E+00
	Euro 6	All	(27)	10-130	0.987	-1.21E+18	1.63E+20	1.79E+18	2.89E+19	1.17E+16	4.09E+18
	Euro 6c	All		10-130	0.987	-1.21E+18	1.63E+20	1.79E+18	2.89E+19	1.17E+16	4.09E+18

Diesel hot emissions

Exercise

Tier 3 emissions factors

Table 3-47: Values of e^{COLD} / e^{HOT} for diesel passenger cars (temperature range -10 °C to 30 °C)

Pollutant or FC	e^{COLD} / e^{HOT}
CO	$1.9 - 0.03\ t_a$
NO_x	$1.3 - 0.013\ t_a$
VOC	$3.1 - 0.09\ t_a$ (1)
PM	$3.1 - 0.1\ t_a$ (2)
Fuel consumption	$1.34 - 0.008\ t_a$

Note
(1) VOC: if ta > 29 °C then e^{COLD} / e^{HOT} > 0.5.
(2) PM: if ta > 26 °C then e^{COLD} / e^{HOT} > 0.5.

Diesel cold emissions

Exercise

Gasoline (2x)		**Diesel (2x)**		**HEV (1x)**	
Euro4		**Euro3**		**Euro4**	
	NOx	NOx	PM	NOx	
a	0.71	2.82	0.0515	-0.01	
b	0.106	0.198	0	0	
c	0	0.0669	-0.00088	0.000654	
d	-0.00158	-0.00143	0	0	
e	0	-0.000463	0.00000812	-0.00000376	
f	0.0000071	0	0	0	
vurban	13.88888889	13.88888889	13.88888889	13.88888889	
vhighway	120	120	120	120	
NOx (g/km) urban	**NOx (g/km) highway**	**NOx (g/km) urban**	**NOx (g/km) highway**	**NOx (g/km) urban**	**NOx (g/km) highway**
0.32757565	-0.078609395	1.053452526	1.003071017	-0.001641975	0.014336
PM (g/km) urban	**PM (g/km) highway**	**PM (g/km) urban**	**PM (g/km) highway**		
0.00128	0.00119	0.040844136	0.062828		

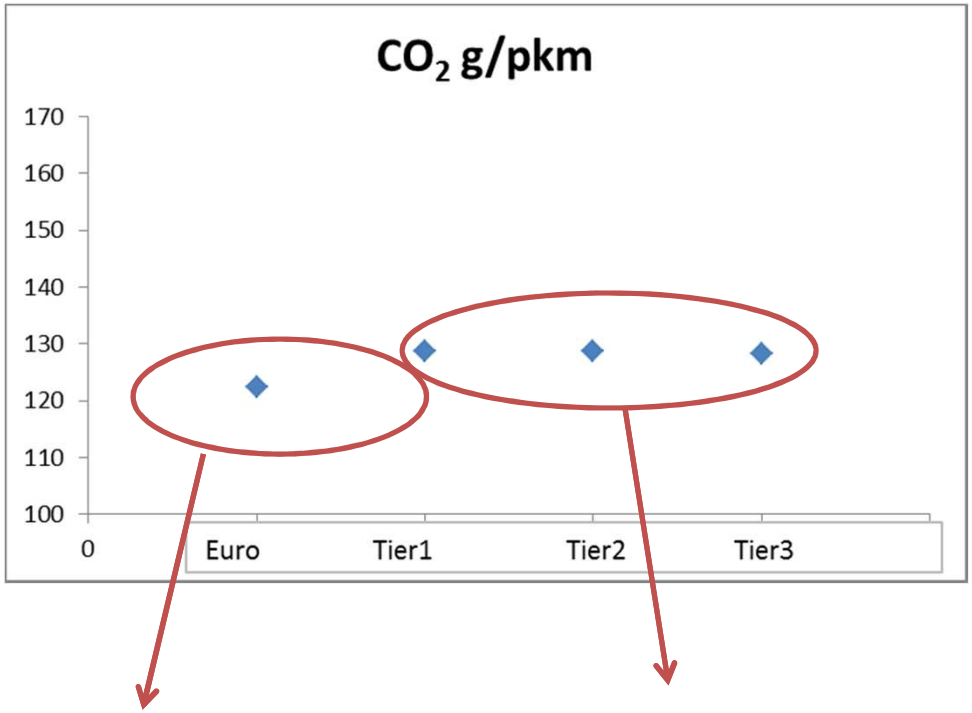
Exercise

New hot emission factors 2017

$$EF = (Alpha \times V^2 + Beta \times V + Gamma + Delta / V) / (Epsilon \times V^2 + Zeta \times V + Eta) \times (1 - RF)$$

For all!!!

Exercise



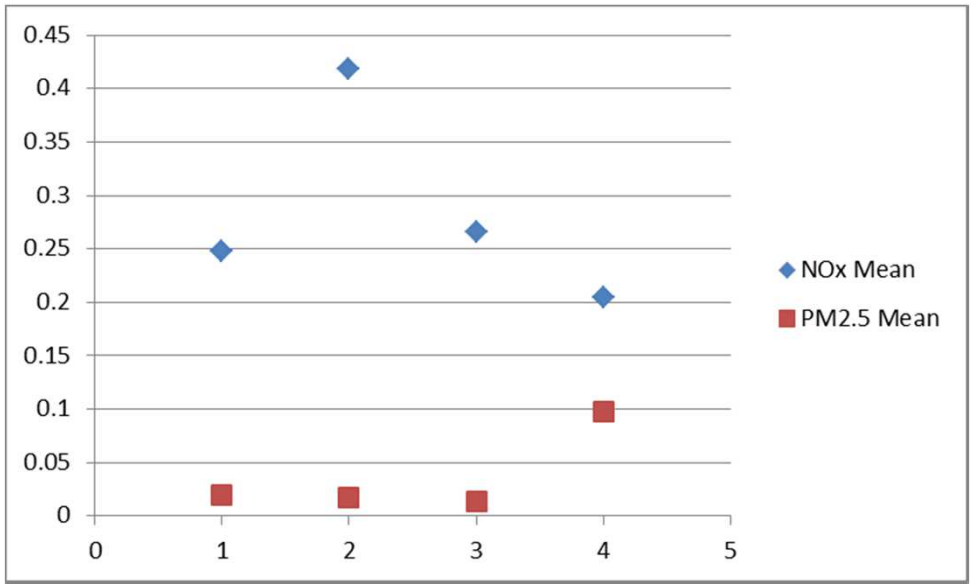
We used gasoline and diesel 3.14 gCO_2/gFuel

They used

gasoline	3.180	gCO2/gFuel
diesel	3.140	

Exercise

g/pkm



Exercise-Conclusion cars

A/C?.....

Lube oil?.....

Ambient temperature?.....

Load?....

Road slope?.....

Euro standard?.....

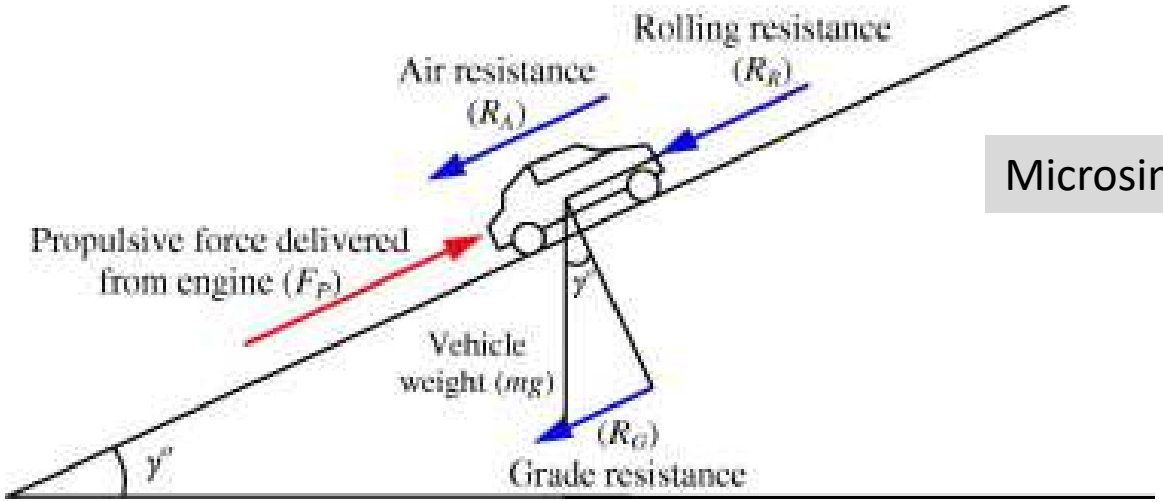
Tier3

Exercise

Conclusions P#4 and P#5 and P#6: Total emissions per year

Emissions/Fleet	Lisbon-Porto TAP	SofLusa Lisboa-Barreiro	Lisbon-Porto 5 Car fleet
			
CO_2 (ton/year)	19 000	16 580	140
NOx (ton/year)	32	415	0.2
PM2.5 (ton/year)	6.5	7.4	0.1

Motor vehicle dynamics



Microsimulation approach

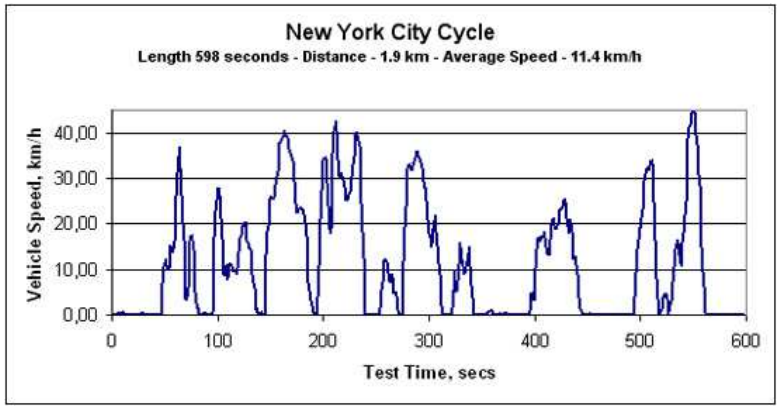
Roling $Rr = k_r(m+m_p)g \bullet \cos\gamma$

Road gradient $Fw = (m+m_p)g \bullet sin\gamma$

Aerodynamics $Ra = 1/2 \bullet \rho C_d A_f v^2$

Propultion $Fp = (k_m \bullet m + m_p) \bullet dv/dt$

Motor vehicle dynamics



Roling k_r

Aerodynamics $C_d A_f$

Propultion k_m

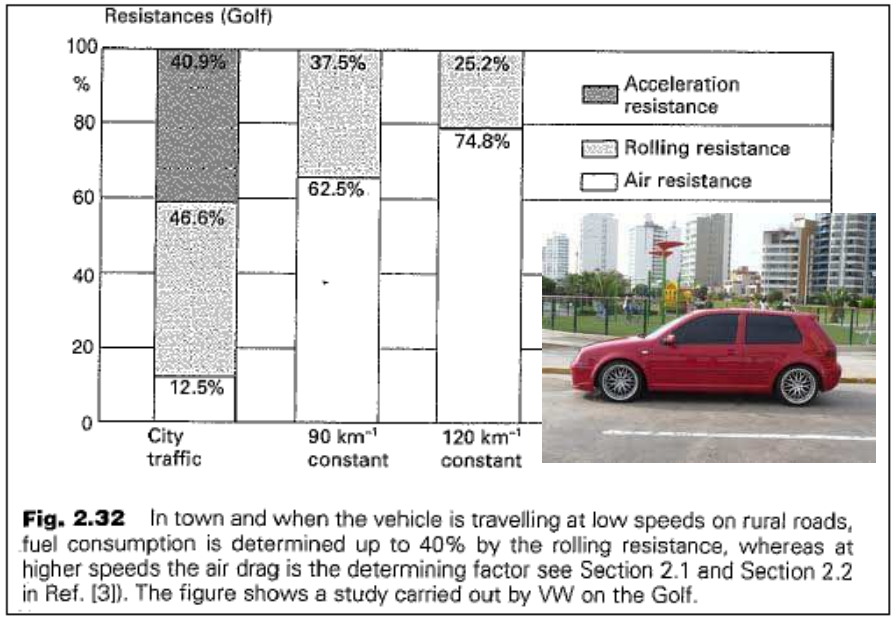
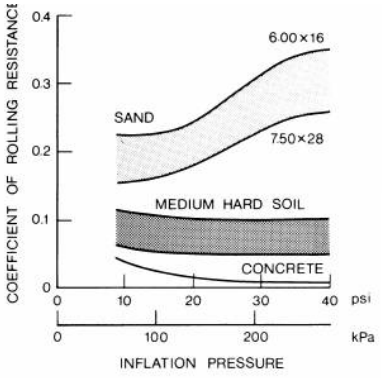
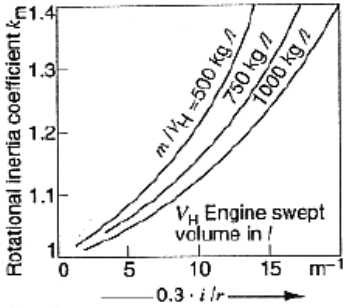


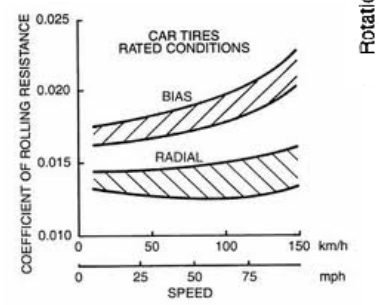
Fig. 2.32 In town and when the vehicle is travelling at low speeds on rural roads, fuel consumption is determined up to 40% by the rolling resistance, whereas at higher speeds the air drag is the determining factor see Section 2.1 and Section 2.2 in Ref. [3]). The figure shows a study carried out by VW on the Golf.

Contribution of Tire Rolling Resistance to Vehicle Fuel Economy Versus Speed
(Reprinted with permission from the Automotive Chassis: Engineering Principles, 2nd Edition, Reed Educational and Professional Publishing Ltd., 2001)

Motor vehicle dynamics





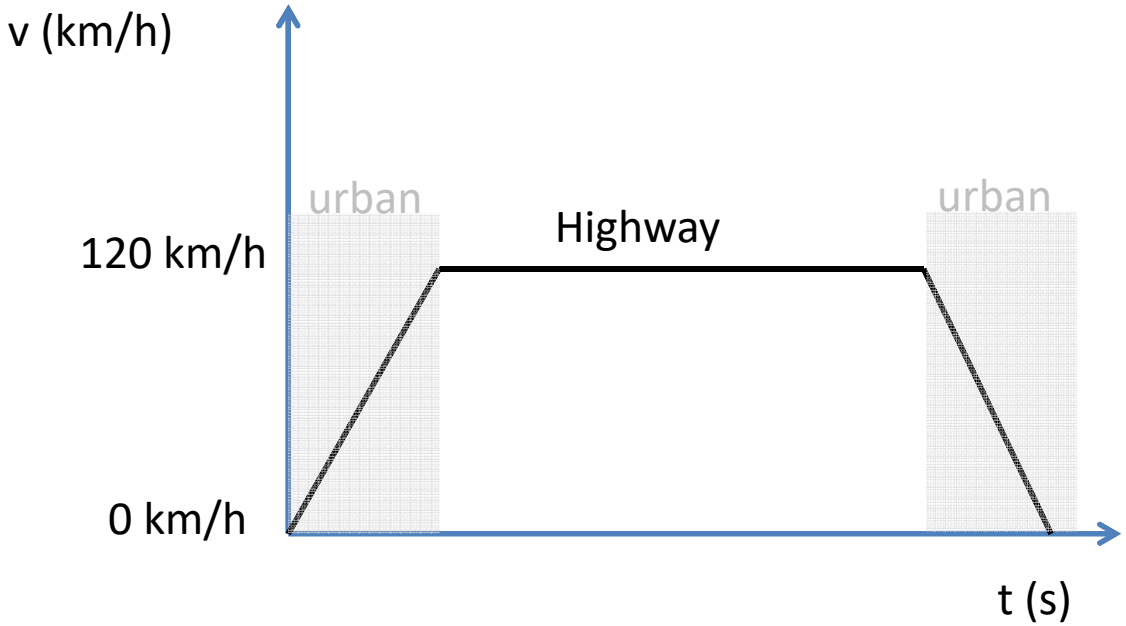


@Bosch Automotive Handbook: 8th Edition

Roling	k_r	0.013	0.01
Aerodynamics	$C_d A_f$	0.35x1.91m^2	0.6x7m^2
Propultion	k_m	1.1	1.13

Exercise

Without refueling info? With GPS info….microsimulation aproach



Driving cycle

v(km/h)	v(m/s)	dist (km)	t(s)	a		
0	0	0	0	2.777778	m/s2	
100	27.77778	0.416667	10			
120	33.33333	0.428194	12			
		299.1436	8986.308	end of constant speed		
			8998.308	end trip		
Vaverage urban		**Vaverage highway**			km/h	
13.88889		120				

Gasoline					**Diesel**					**HEV**				
curb weight (kg)	1200				curb weight (kg)	1500				curb weight (kg	1400			
gama	0				gama	0				gama	0			
kr	0.013				kr	0.013				kr	0.013			
CD*Af	0.6				CD*Af	0.6				CD*Af	0.4			
km	1				km	1				km	1			
passenger (kg)	70				passenger (kg)	70				passenger (kg)	70			
g (m/s2)	9.8				g (m/s2)	9.8				g (m/s2)	9.8			
	1.2					1.2					1.2			
	at 0 s	at 12s	at 8986 s	at end		at 0 s	at 12s	at 8986 s	at end		at 0 s	at 12s	at 8986 s	at end
Roling	0	161.798	161.798	0	Roling	0	200.018	200.018	0	Roling	0	187.278	187.278	
Drag	0	400	400	0	Drag	0	400	400	0	Drag	0	266.6667	266.6667	
climbing	0	0	0	0	climbing	0	0	0	0	climbing	0	0	0	0
Acceleration	0	3527.7778	0	0	Acceleration	0	4361.111	0	0	Acceleration	0	4083.333	0	

Motor vehicle dynamics

Force (N)	0	4089.5758	561.798	0	Force (N)	0	4961.129	600.018	0	Force (N)	0	4537.278	453.9447	0
Power (W)	0	136319.19	18726.6	0	Power (W)	0	165371	20000.6	0	Power (W)	0	151242.6	15131.49	0
Energy wheels (MJ)		168.87042			Energy wheels (MJ)		180.4776			Energy wheels (MJ)		136.6974	135.79	
Energy tank (MJ)		711.03336			Energy tank (MJ)		633.2548			Energy tank (MJ)		411.1201	408.3909	
Energy tank (MJ/pkm)		2.3701112			Energy tank (MJ/pkm)		2.110849			Energy tank (MJ/pkm)		1.3704	1.361303	
													0% energy recovery	100% ener

Engine efficiency	25	30	35

Fleet average (MJ/pkm)	**2.06**

Motor vehicle dynamics

Fleet average (MJ/pkm) **2.06**

Possibilities for emissions

EU Emission Standards for Passenger Cars (Category M_1*)

Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
		g/km					#/km
Compression Ignition (Diesel)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)	-
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08	-
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10	-
Euro 3	2000.01	0.64	-	0.56	0.50	0.05	-
Euro 4	2005.01	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009.09[b]	0.50	-	0.23	0.18	0.005[f]	-
Euro 5b	2011.09[c]	0.50	-	0.23	0.18	0.005[f]	6.0×10^{11}
Euro 6	2014.09	0.50	-	0.17	0.08	0.005[f]	6.0×10^{11}
Positive Ignition (Gasoline)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-	-
Euro 2	1996.01	2.2	-	0.5	-	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-	-
Euro 4	2005.01	1.0	0.10	-	0.08	-	-
Euro 5	2009.09[b]	1.0	0.10[d]	-	0.06	0.005[e,f]	-
Euro 6	2014.09	1.0	0.10[d]	-	0.06	0.005[e,f]	6.0×10^{11} [e,g]

* At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
a. until 1999.09.30 (after that date DI engines must meet the IDI limits)
b. 2011.01 for all models
c. 2013.01 for all models
d. and NMHC = 0.068 g/km
e. applicable only to vehicles using DI engines
f. 0.0045 g/km using the PMP measurement procedure
g. 6.0×10^{12} 1/km within first three years from Euro 6 effective dates

Euro Standards

Tier 1

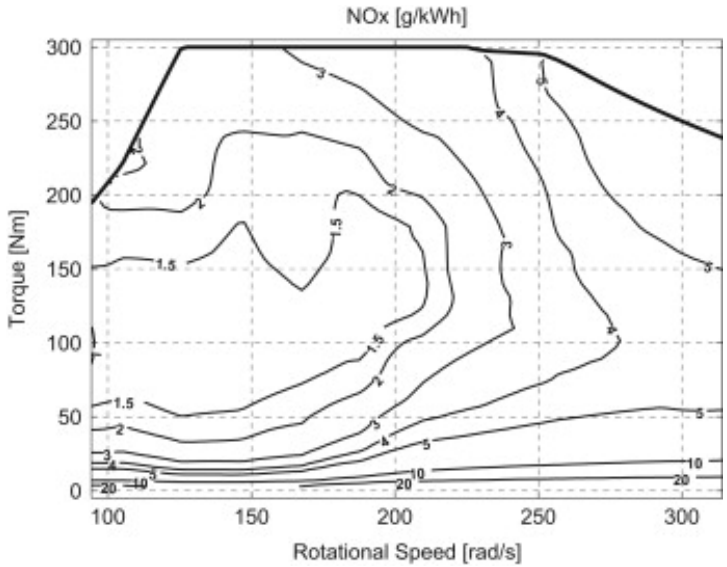
EF = f(fuel consumption)

Tier 2

EF = f(vehicle category & standard)

Motor vehicle dynamics

Possibilities for emissions Microsimulation



Motor vehicle dynamics

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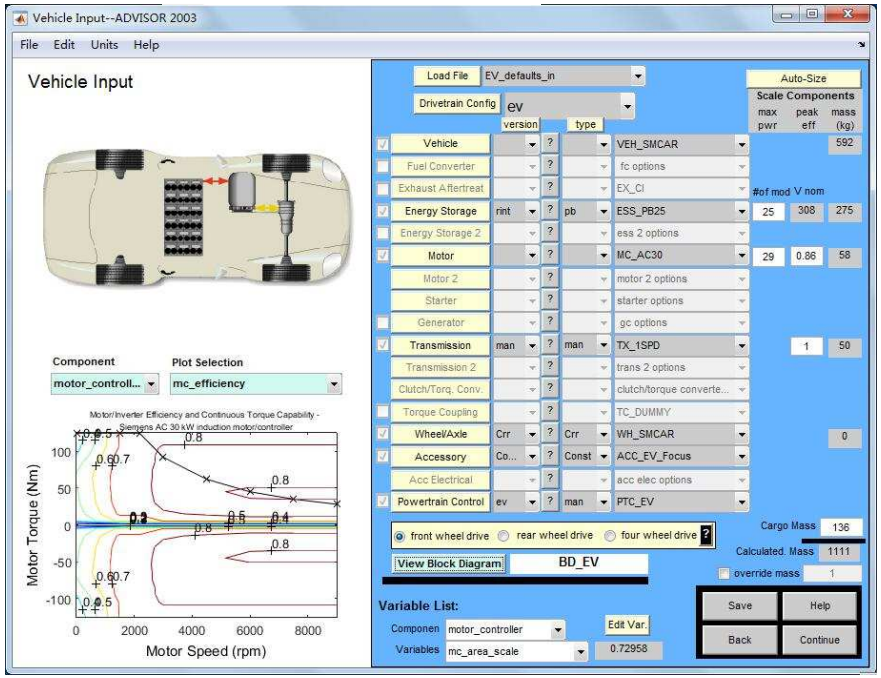
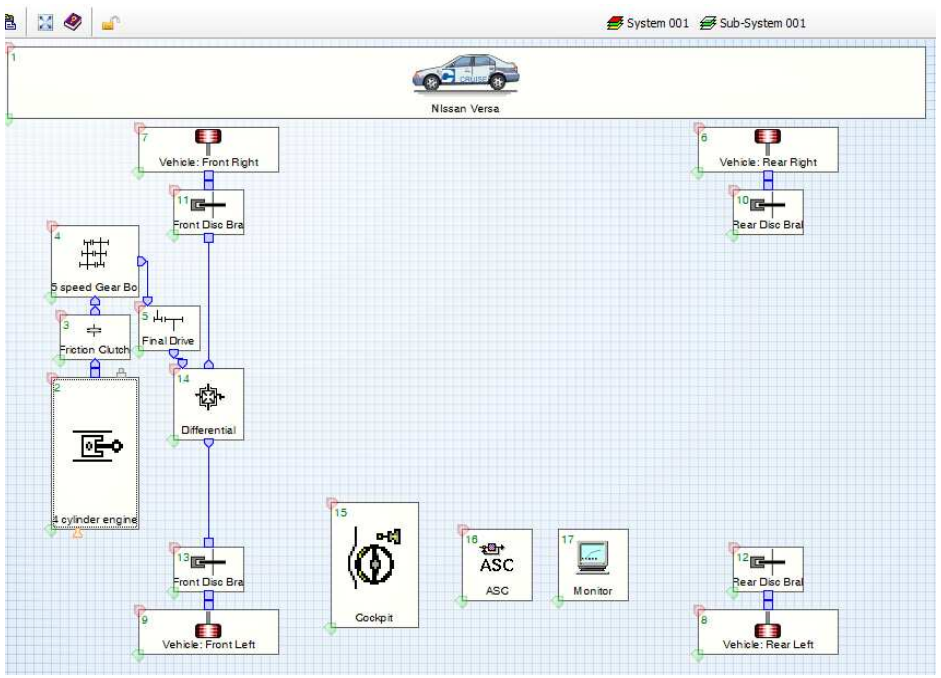
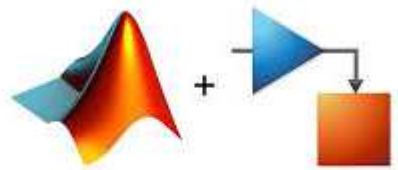


AVL CRUISE

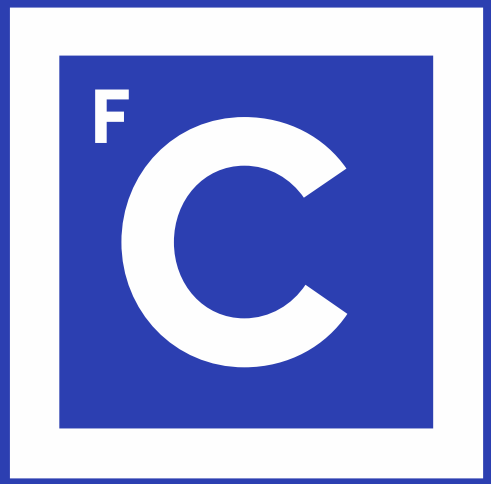




combine MATLAB code and Simulink models together.

python™

Thanks



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