Ciências
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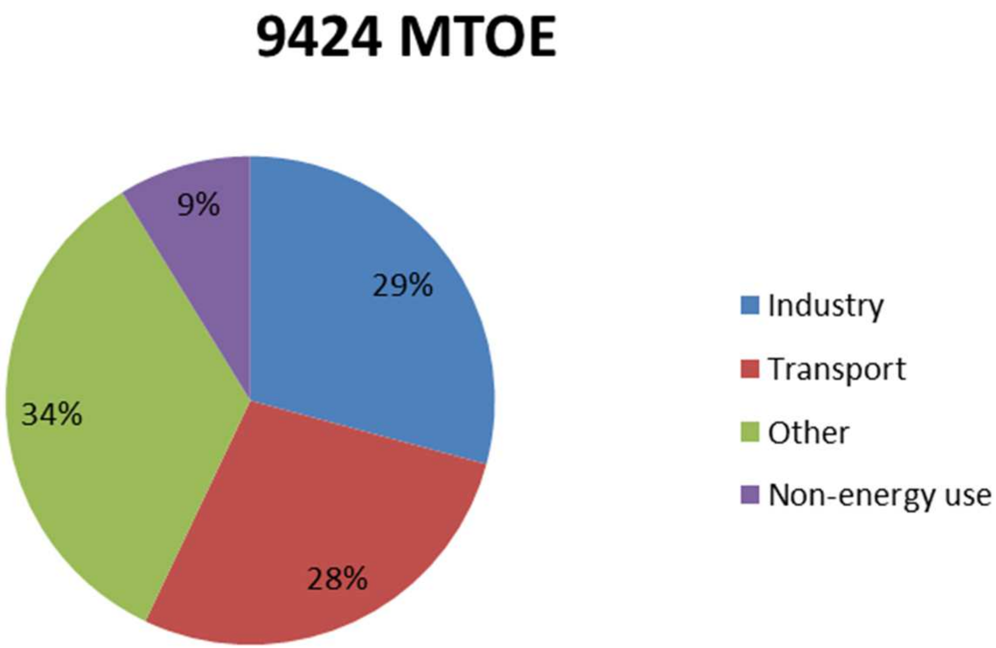
Faculdade
de Ciências
da Universidade
de Lisboa

DISCIPLINA MIEA 2016

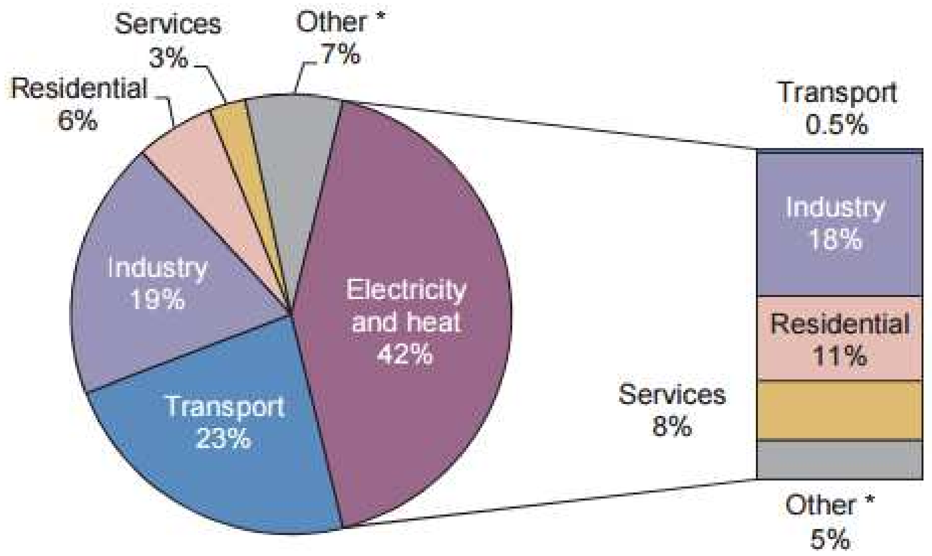
move green

Sustainable Mobility

- **Energy consumption by transport sector**



Emissions



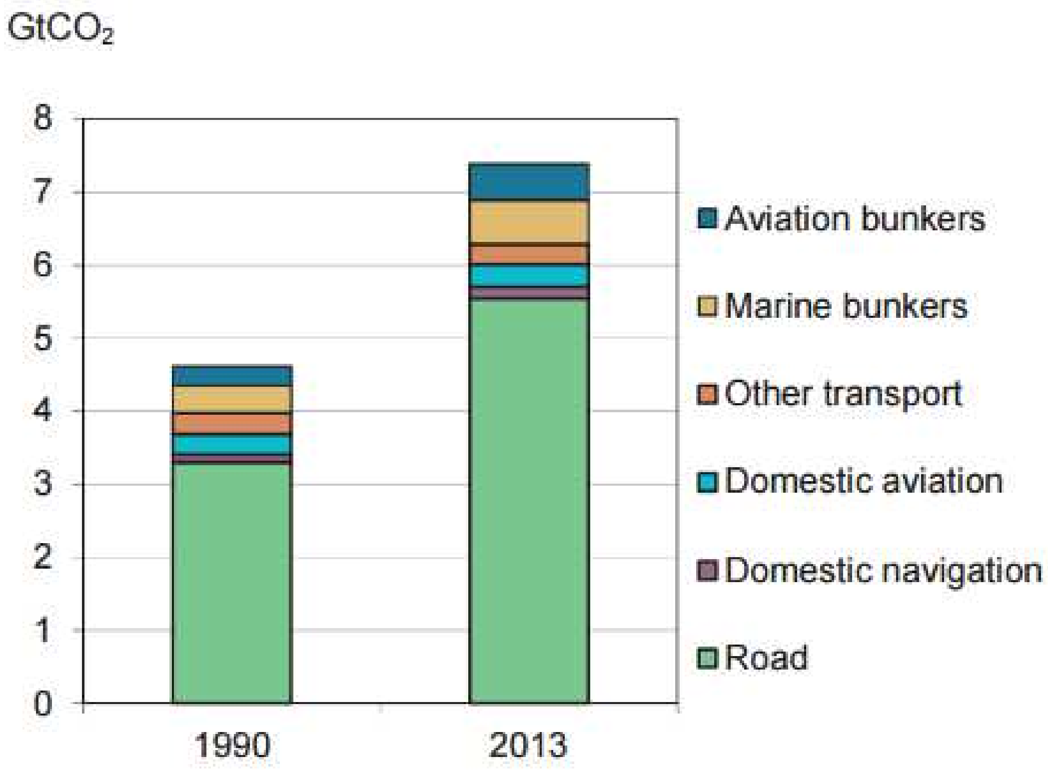
Note: Also shows allocation of electricity and heat to end-use sectors.

* Other includes agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

World CO_2 emissions by sector in 2013

Note: Also shows allocation of electricity and heat to end-use sectors. * Other includes agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

Shares within transport sector



LOCAL EMISSIONS

Transports, local emissions

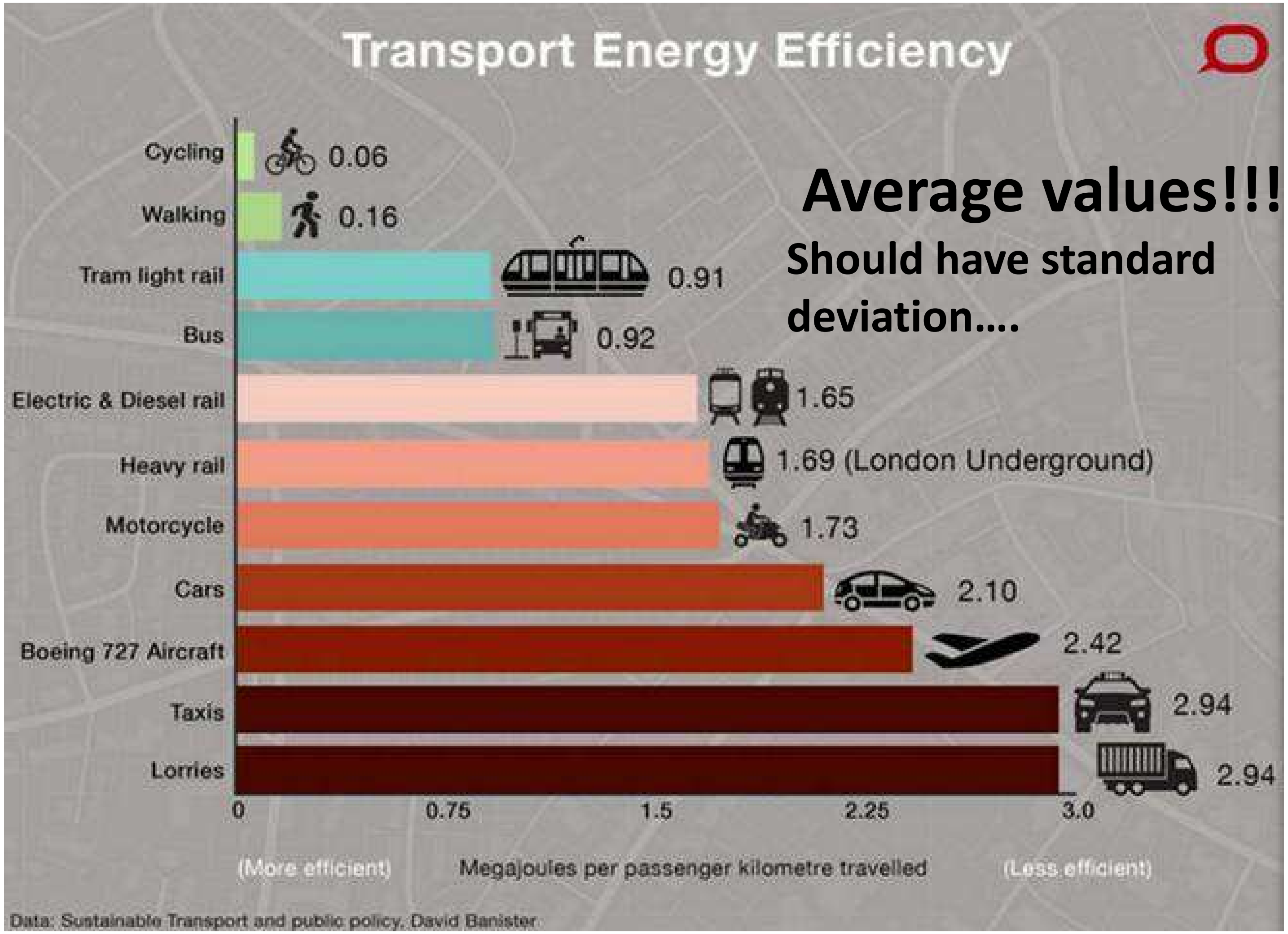
LOCAL AIR QUALITY EMISSIONS (EUROPE)

					NON-TRANSPORT	
NOx	32.9%	0.9%	19.1%	4.5%	NOx	42.6%
CO	26.6%	0.2%	2.3%	0.7%	CO	70.2%
SOx	0.1%	0.0%	20.9%	0.5%	SOx	78.5%
VOLATILE ORGANIC COMPOUNDS	15.4%	0.14%	2.52%	0.40%	VOLATILE ORGANIC COMPOUNDS	81.54%
FINE PARTICLES (PM2.5)	14.2%	0.4%	11.4%	0.6%	FINE PARTICLES (PM2.5)	73.4%

In % of total emissions | source: European Environment Agency, 2013

THANKS TO IMPROVEMENTS IN AIRCRAFT TECHNOLOGY,
THE IMPACT OF AIRCRAFT EMISSIONS ON LOCAL AIR QUALITY
IS RELATIVELY LOW COMPARED TO OTHER SOURCES.

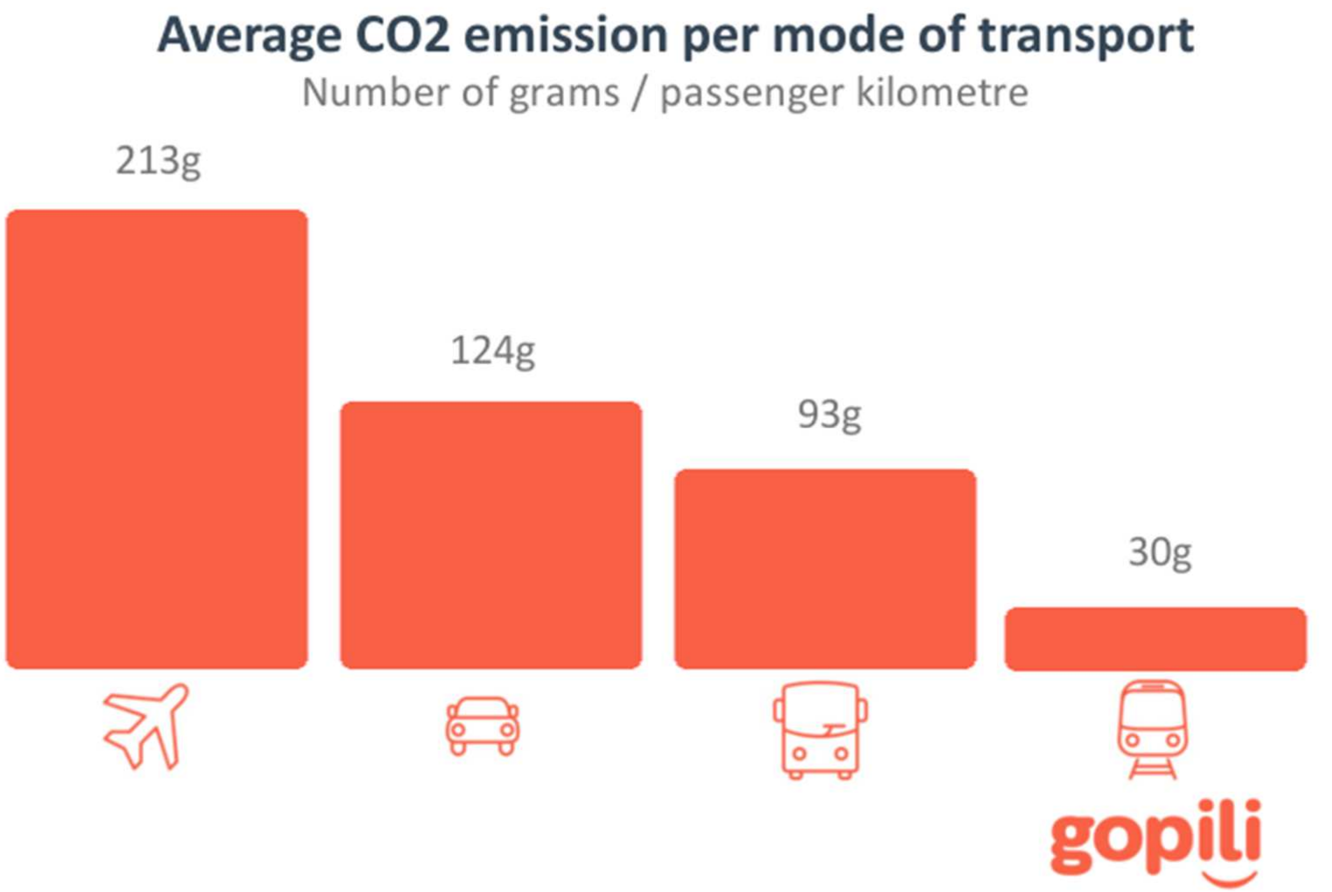
UK transport energy efficiency



Average values!!!!!

Should have standard deviation….

Emissions


Average CO2 emission per mode of transport
Number of grams / passenger kilometre
213g
124g
93g
30g
gopili

Fleet impacts

Vehicle activity x Occupation x Factor x days/year

km

e.g. 1.5 people/car

e.g. 256 days/year

Energy and Emission factors

MJ/pkm and g/pkm

Energy MJ/year	Emissions g/year

Emissions

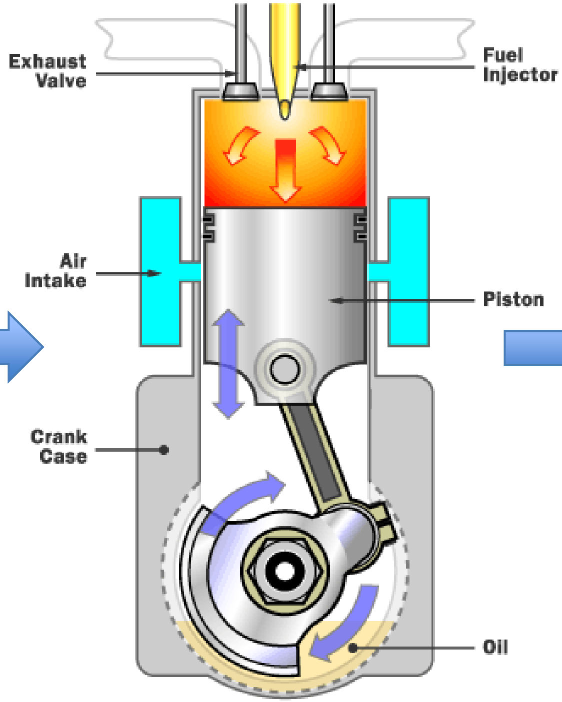
Local

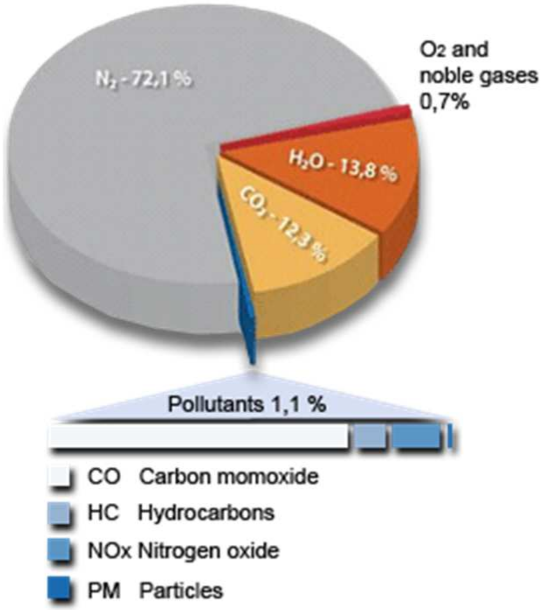
HC, CO, NOx and PM

Global

CO_2 equivalent or GHG

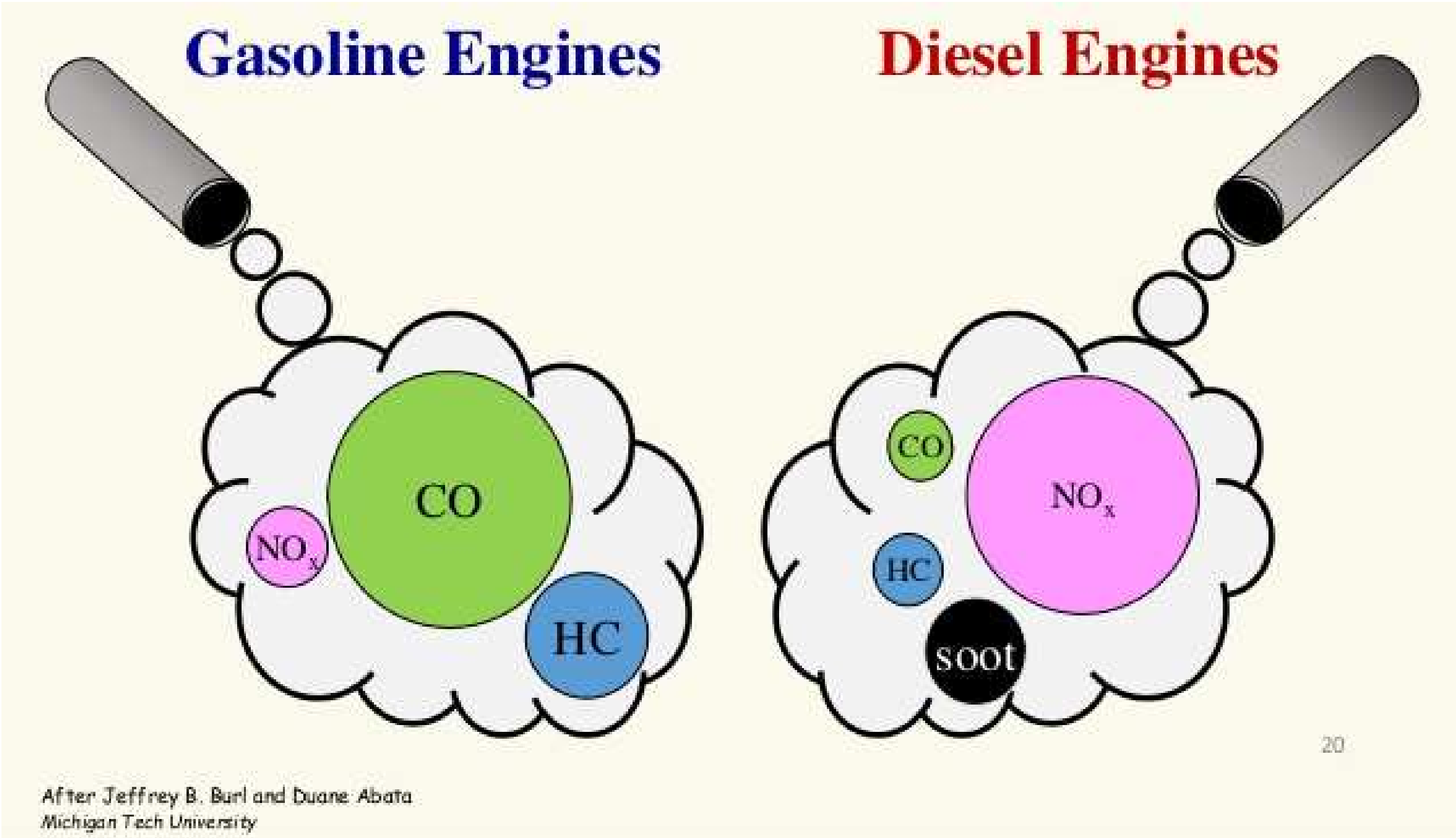
Why do we have emissions???



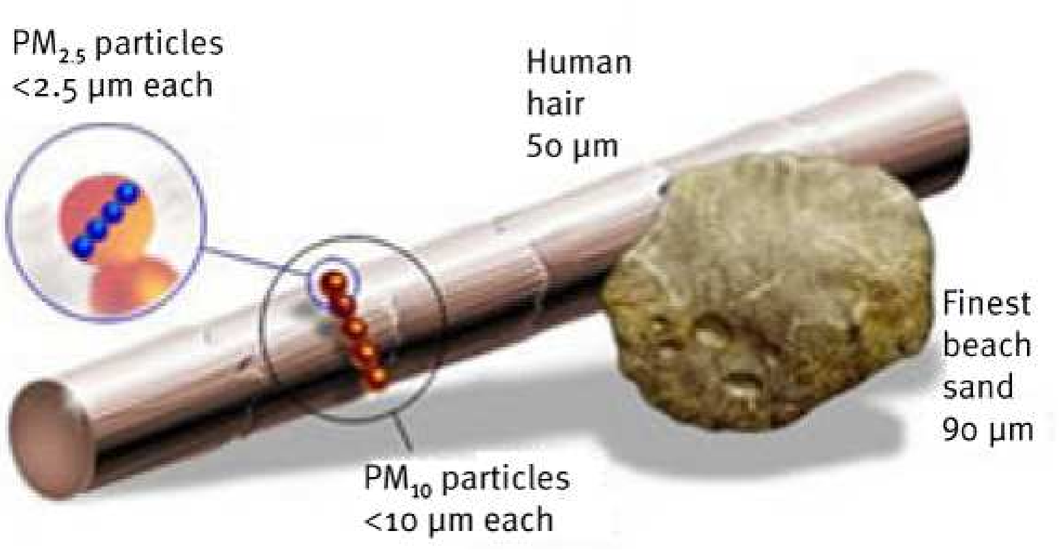


MOBILE COMBUSTION

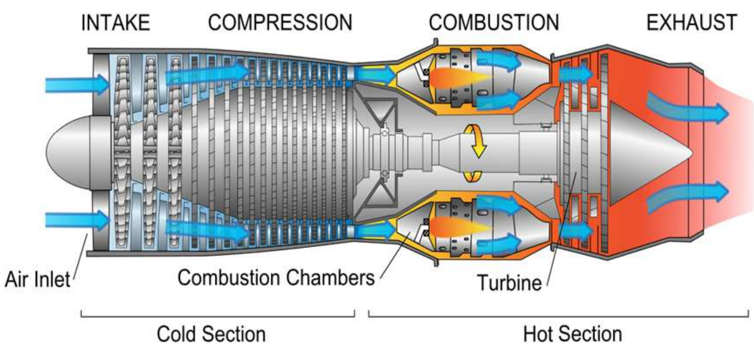
LOCAL EMISSIONS

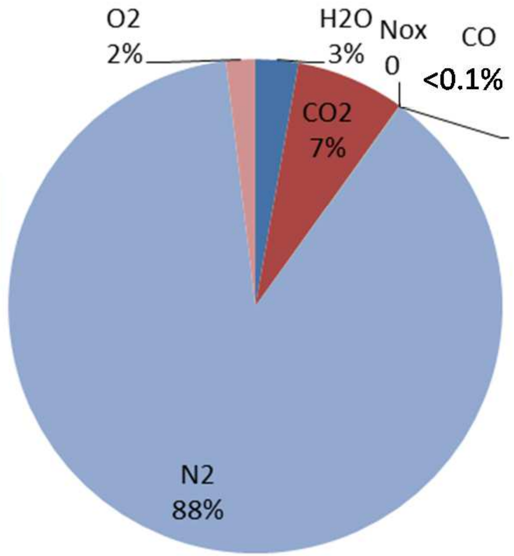


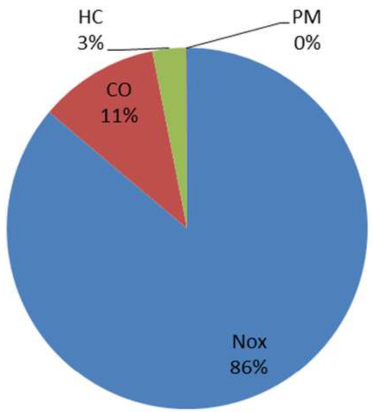
PM2.5 and PM10



Why do we have emissions???







MOBILE COMBUSTION

Why do we have emissions???

Products of ideal combustion

$$C_nH_m + S + N_2 + O_2 \rightarrow CO_2 + H_2O + N_2 + O_2 + NO_x + CO + SO_x + Soot + UHC$$

Fuel

Air

Products of non-ideal combustion

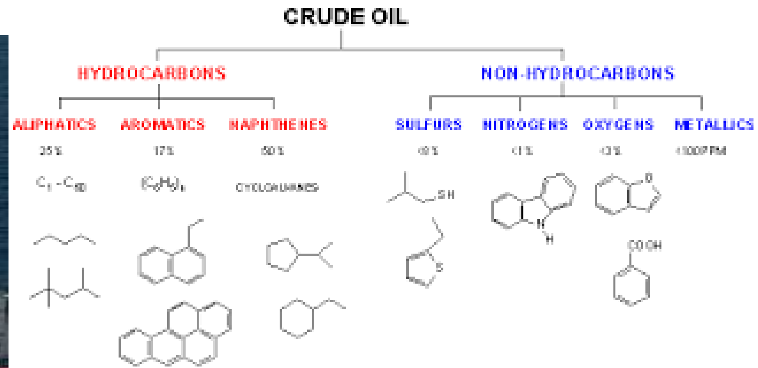
NO_x: Affects ozone (O_3) concentration
CO_2: Absorbs outgoing infrared radiation
CO: Toxic
Soot: Visible

Emissions

1 toe = 41.868 GJ or 11.63 MWh

the amount of energy released by burning one tonne of crude oil

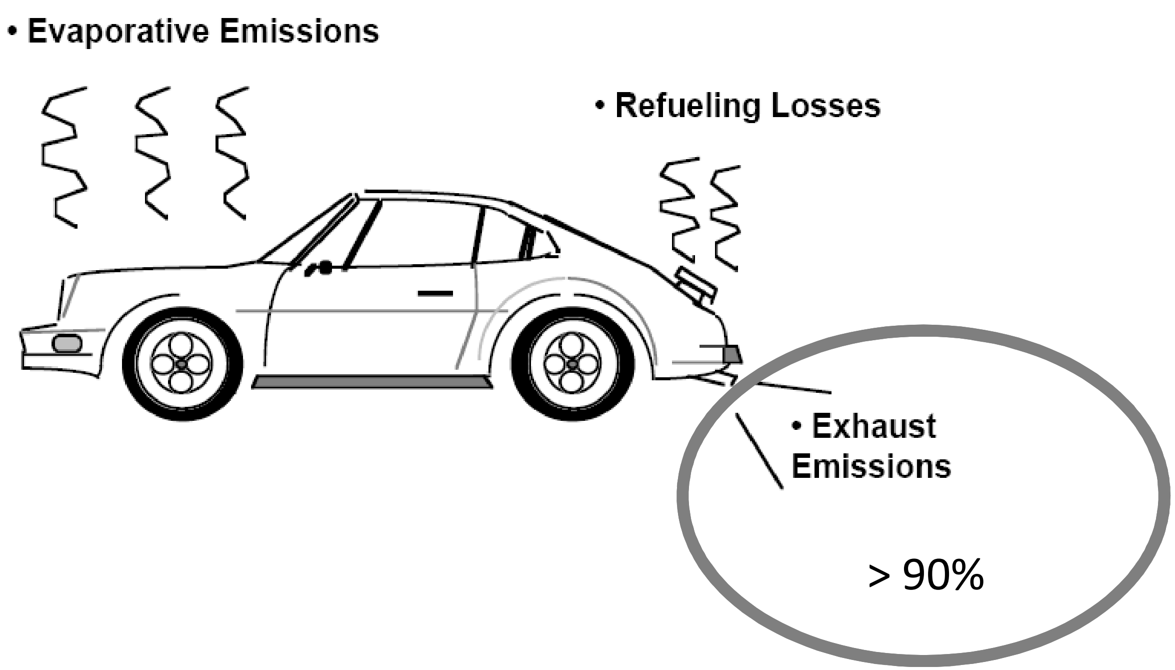
1 toe ~ 2.5 tCO_2



Carbon - 83 to 87%
Hydrogen - 10 to 14%
Nitrogen - 0.1 to 2%
Oxygen - 0.05 to 1.5%
Sulfur - 0.05 to 6.0%
Metals - < 0.1%

Emissions

		Density at STP (kg/m³)	Ratio of HHV to LHV energy content	Net Calorific Value / LHV (MJ/L)	Net Calorific Value / LHV (MJ/kg)	Gross Calorific Value / HHV (MJ/L)	Gross Calorific Value / HHV (MJ/kg)	Carbon Intensity (g CO_2-eq / MJ LHV)
Crude Oil		856 ± 24	1.052 ± 0.001	36.84 ± 1.05	43.05 ± 1.40	38.76 ± 1.10	45.30 ± 1.47	73.5 ± 2.6
Petrol / Gasoline		741 ± 4	1.063 ± 0.015	32.70 ± 0.44	44.15 ± 0.74	34.77 ± 0.47	46.94 ± 0.70	70.8 ± 4.4
Diesel		837 ± 8	1.063 ± 0.011	35.94 ± 0.45	42.91 ± 0.46	38.19 ± 0.47	45.60 ± 0.49	74.3 ± 2.3
Fuel Oil		959 ± 17	1.058 ± 0.008	39.21 ± 1.09	40.87 ± 0.94	41.50 ± 1.15	43.26 ± 1.00	77.8 ± 2.1
LPG		533 ± 18	1.077 ± 0.008	24.67 ± 0.80	46.28 ± 0.74	26.57 ± 0.86	49.84 ± 0.80	63.9 ± 2.1
Kerosene		807 ± 6	1.053 ± 0.001	35.24 ± 0.41	43.69 ± 0.51	37.10 ± 0.43	45.99 ± 0.54	72.0 ± 1.8
	(35 MPa)	23.65 ± 0.09		2.837 ± 0.003		3.355 ± 0.004		
Hydrogen	(70 MPa)	39.69 ± 0.16	1.183 ± 0.001	4.761 ± 0.005	119.95 ± 0.13	5.631 ± 0.006	141.88 ± 0.16	0
	(liquid)	72.41 ± 0.72		8.685 ± 0.010		10.273 ± 0.011		
		(kg/m³)	**(HHV / LHV)**		**(MJ/kg)**		**(MJ/kg)**	**(g/MJ LHV)**
Coal			1.050 ± 0.004	-	25.75 ± 2.64	-	27.05 ± 2.77	95.7 ± 7.0
		(kg/m³)	**(HHV / LHV)**	**(MJ/m³)**	**(MJ/kg)**	**(MJ/m³)**	**(MJ/kg)**	**(g/MJ LHV)**
Natural Gas		0.768 ± 0.039	1.109 ± 0.003	35.22 ± 2.22	45.86 ± 3.95	39.05 ± 2.47	50.84 ± 4.38	56.9 ± 3.4
Hydrogen	(1 atm.)	0.0838 ± 0.0008	1.183 ± 0.001	10.05 ± 0.01	119.95 ± 0.13	11.88 ± 0.01	141.88 ± 0.16	0



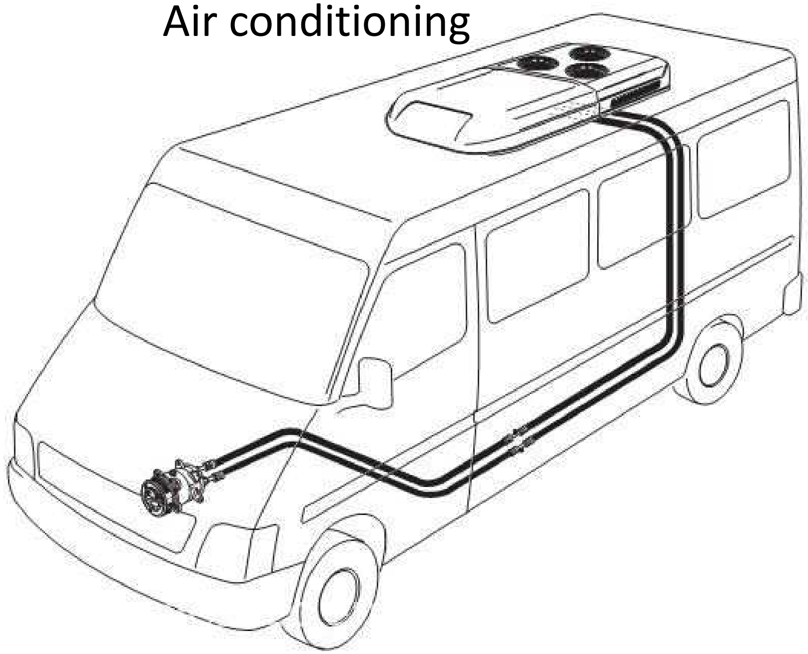
MOBILE COMBUSTION

Global

CO_2 equivalent

Refrigerante	Fórmula química	CO2eq 100 anos
HFC-134a	CH2FCF3	1430
SF6	SF6	22800
PFC	CF4	7390

Air conditioning

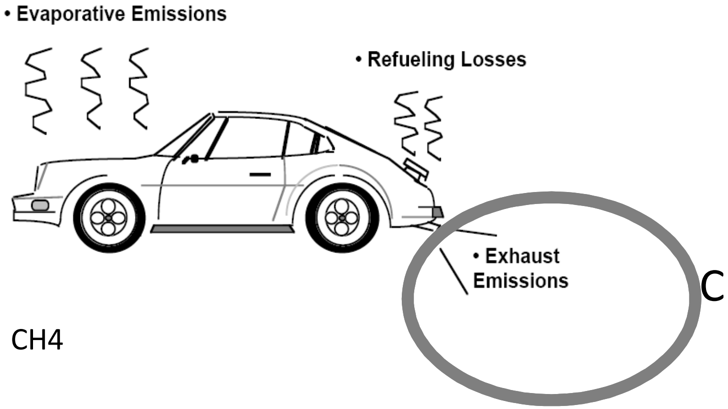


HFC-134a ~ 3-5% of tailpipe CO_2 or 6-8 g/km of $CO_{2\ eq}$

Emissions

Global

CO_2



CO_2, N2O, CH4

Tailpipe

CH4, N2O ~ 0.3-3% of tailpipe CO2

TABLE 1.8

Direct Greenhouse Gas Emissions from Passenger Cars on Petrol, Diesel, LPG and CNG under Real-World Driving Conditions

Fuel	CO_2 (g/km)	CH_4 (g/km)	N_2O (g/km)	GHG Emission (g of CO_2 Equivalent/km)
Petrol	208.1	0.009	0.003	209.2
Diesel	180.5	0.004	0.007	182.7
LPG	189.3	0.007	0.003	190.4
CNG	168.6	0.0074	0.001	170.6

Source: Adapted from P. Hendriksen et al., Evaluation of the environmental performance of modern passenger cars running on petrol, diesel, automotive LPG and CNG, TNO-report 03.OR.VM.055.1/PHE, TNO Automotive, December 2003.

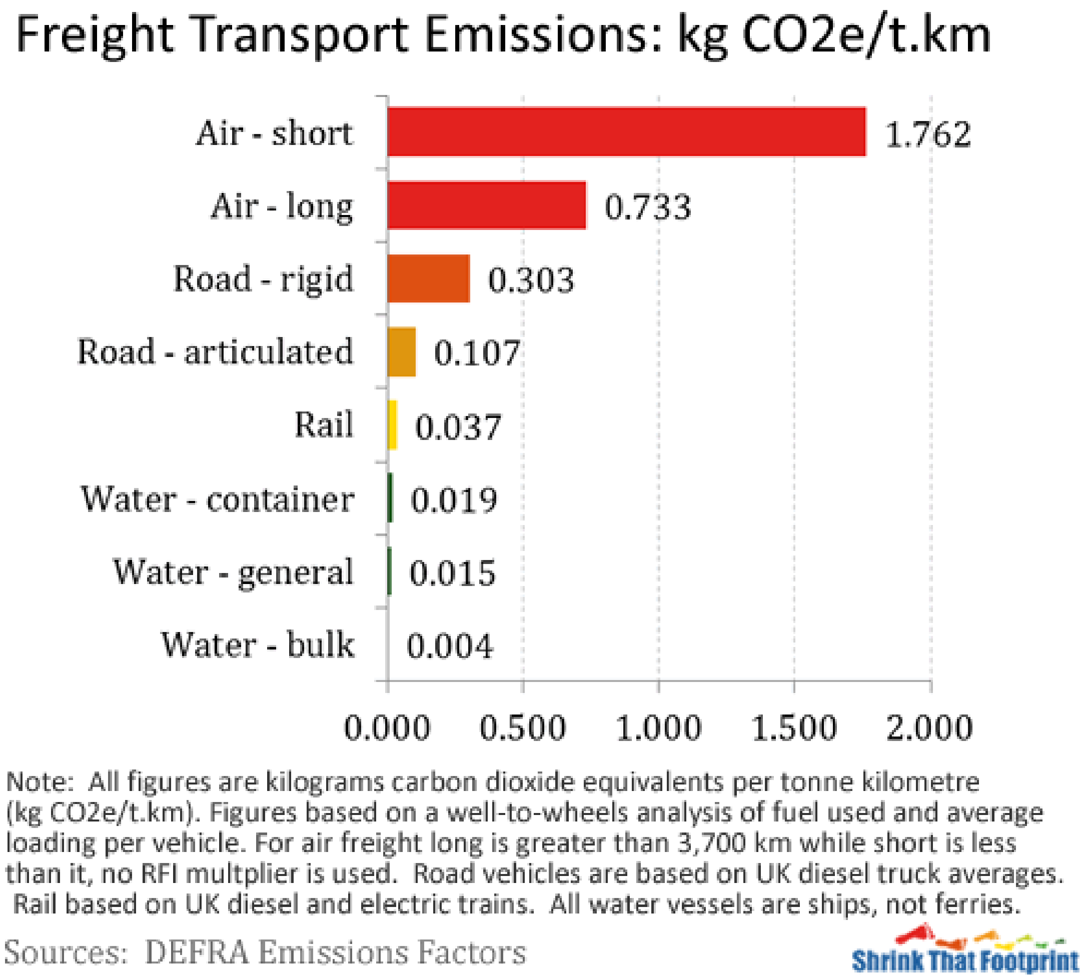
CO_2 equivalent

$$CO_2\ \text{eq [kg]} = \sum_i^n (GWP_{100} * \text{Emissioni } \textbf{[kg]})$$

Intergovernmental Panel on Climate Change (IPCC)

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	RadiativeEfficiency (W m^{-2} ppb^{-1})	Global Warming Pote for Given Time Horizo			
				SAR[‡] (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	*See below*[a]	[b]*1.4×10^{-5}*	*1*	*1*	*1*	*1*
Methane[c]	CH_4	*12*[c]	*3.7×10^{-4}*	*21*	*72*	*25*	*7.6*
Nitrous oxide	N_2O	*114*	*3.03×10^{-3}*	*310*	*289*	*298*	*153*
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	*45*	*0.25*	*3,800*	*6,730*	*4,750*	*1,620*
CFC-12	CCl_2F_2	*100*	*0.32*	*8,100*	*11,000*	*10,900*	*5,200*
CFC-13	$CClF_3$	*640*	*0.25*		*10,800*	*14,400*	*16,400*
CFC-113	CCl_2FCClF_2	*85*	*0.3*	*4,800*	*6,540*	*6,130*	*2,700*
CFC-114	$CClF_2CClF_2$	*300*	*0.31*		*8,040*	*10,000*	*8,730*
CFC-115	$CClF_2CF_3$	*1,700*	*0.18*		*5,310*	*7,370*	*9,990*
Halon-1301	$CBrF_3$	*65*	*0.32*	*5,400*	*8,480*	*7,140*	*2,760*
Halon-1211	$CBrClF_2$	*16*	*0.3*		*4,750*	*1,890*	*575*
Halon-2402	$CBrF_2CBrF_2$	*20*	*0.33*		*3,680*	*1,640*	*503*
Carbon tetrachloride	CCl_4	*26*	*0.13*	*1,400*	*2,700*	*1,400*	*435*

Emissions


Freight Transport Emissions: kg CO2e/t.km
Air - short
1.762
Air - long
0.733
Road - rigid
0.303
Road - articulated
0.107
Rail
0.037
Water - container
0.019
Water - general
0.015
Water - bulk
0.004
0.000
0.500
1.000
1.500
2.000
Note: All figures are kilograms carbon dioxide equivalents per tonne kilometre (kg CO2e/t.km). Figures based on a well-to-wheels analysis of fuel used and average loading per vehicle. For air freight long is greater than 3,700 km while short is less than it, no RFI multplier is used. Road vehicles are based on UK diesel truck averages. Rail based on UK diesel and electric trains. All water vessels are ships, not ferries.
Sources: DEFRA Emissions Factors
Shrink That Footprint

Energy consumption….MJ/pkm

EMEP/EEA air pollutant emission inventory guidebook

EEA Report | No 21/2016

EMEP/EEA air pollutant emission inventory guidebook 2016

Technical guidance to prepare national emission inventories

ISSN 1977-8449

Energy consumption….MJ/pkm

EMEP/EEA air pollutant emission inventory guidebook

- Part B: sectoral guidance chapters
  - 1. Energy
    - 1.A Combustion
      - 1.A.1 Energy industries [2.4 MB]
      - 1.A.2 Manufacturing industries and construction [893.2 KB]
      - 1.A.3.a Aviation 2016 [1.5 MB]
      - 1.A.3.b.i-iv Road transport 2016 [3.3 MB]
      - 1.A.3.b.i-iv Road transport Annex HDVs 2016 [3.0 MB]
      - 1.A.3.b.v Gasoline evaporation 2016 [861.2 KB]
      - 1.A.3.b.vi-vii Road tyre and brake wear 2016 [542.7 KB]
      - 1.A.3.c Railways 2016 [476.0 KB]
      - 1.A.3.d Navigation (shipping) 2016 [804.2 KB]
      - 1.A.3.e.i Pipeline transport 2016 [93.3 KB]
      - 1.A.4 Small combustion 2016 [3.5 MB]
      - 1.A.4 Non road mobile machinery 2016 [1.7 MB]
      - 1.A.4 Non road mobile machinery Annex [99.6 KB]

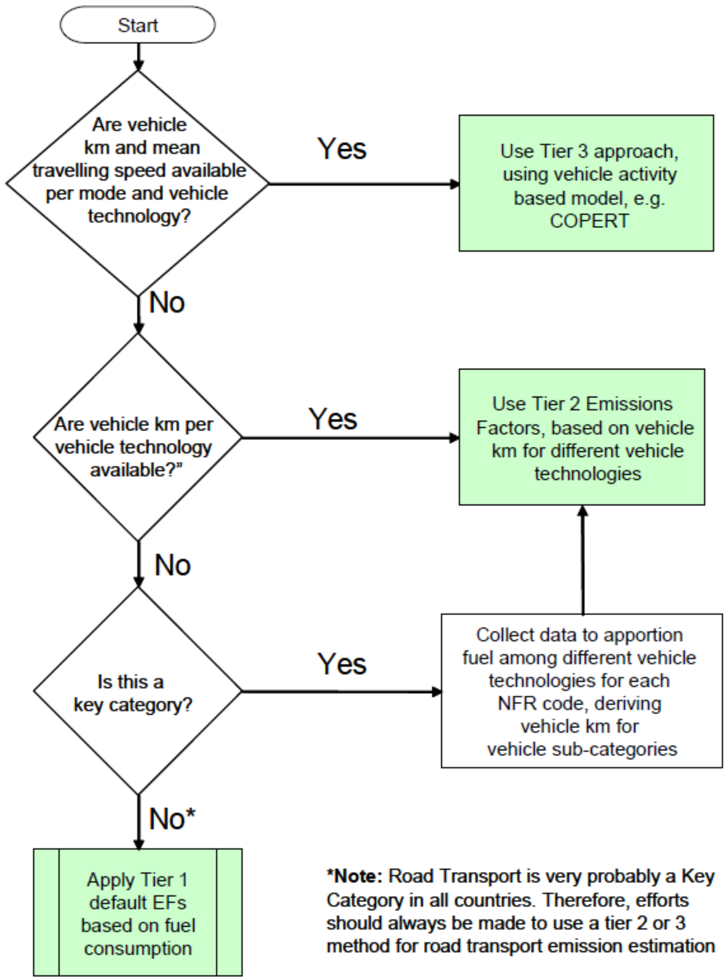
Not electric rail!

Road transport

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

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

Ciências ULisboa

Air transport

Table 3. Airport emissions inventory results.

Table 3 Airport Emissions Inventory Results						
Sources	Pollutants (tons/year)					
	CO	VOC	NO_x	SO_x	PM_{10}	$PM_{2.5}$
Aircraft	718	146	482	59.7	7.3	7.3
APUs	22.8	1.6	12.7	2.2	2.2	2.2
GSE	81.8	6.3	51.0	0.4	5.9	5.7
Stationary sources	3.6	0.2	4.3	0.1	5.9	5.7
Motor vehicles	261	6.2	35.1	0.8	2.6	1.2
Totals	1,087	160	585	63.1	78.2	76.6

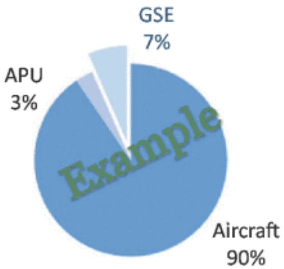


Figure 2. Airport NO_x emissions.

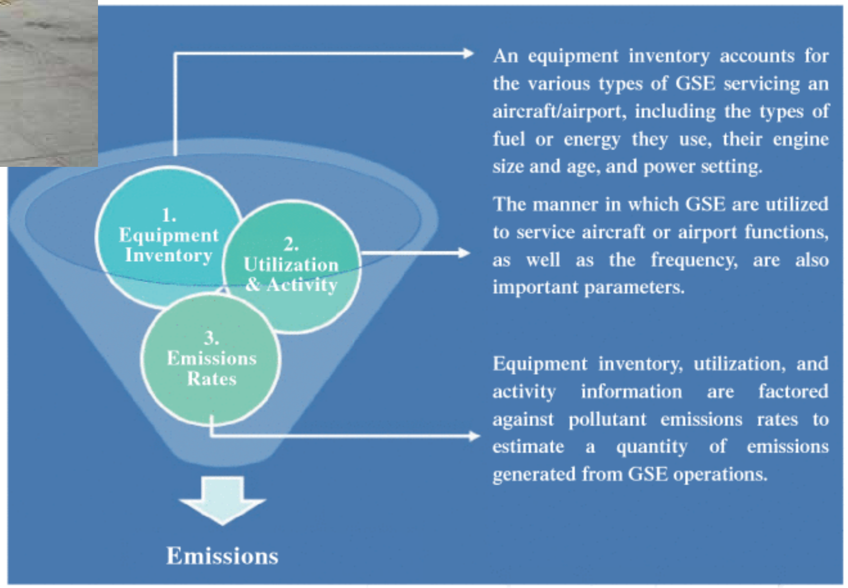
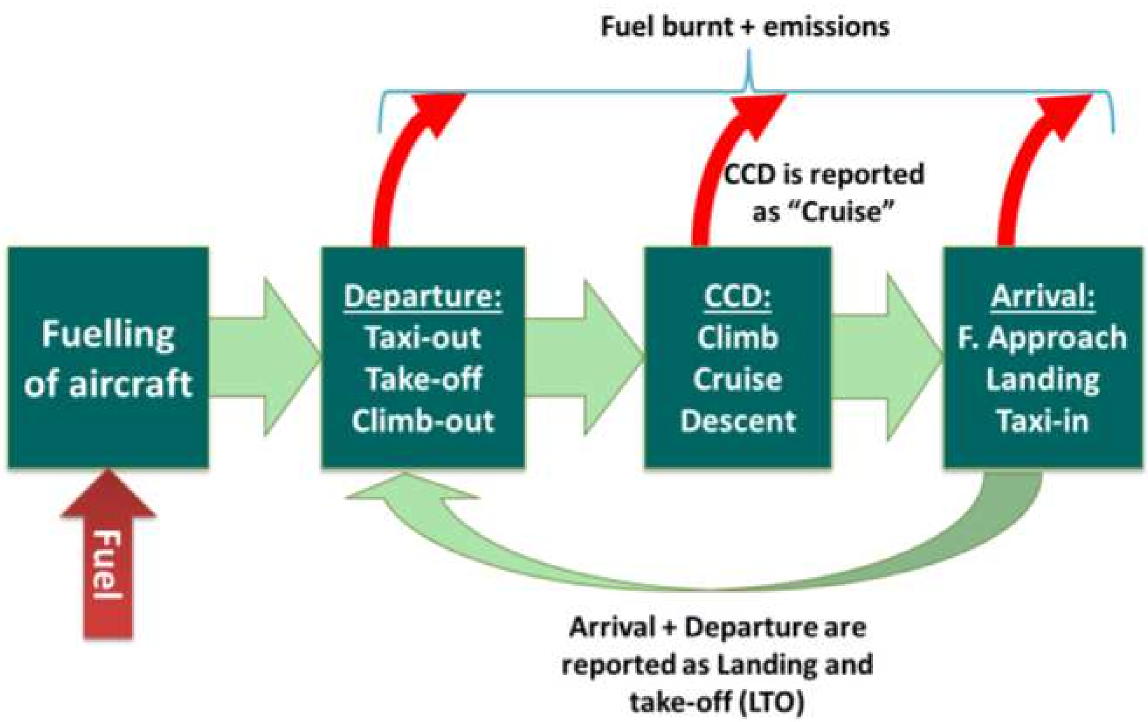


Figure 3. What is a GSE emissions inventory?

Ground Supporting Equipment

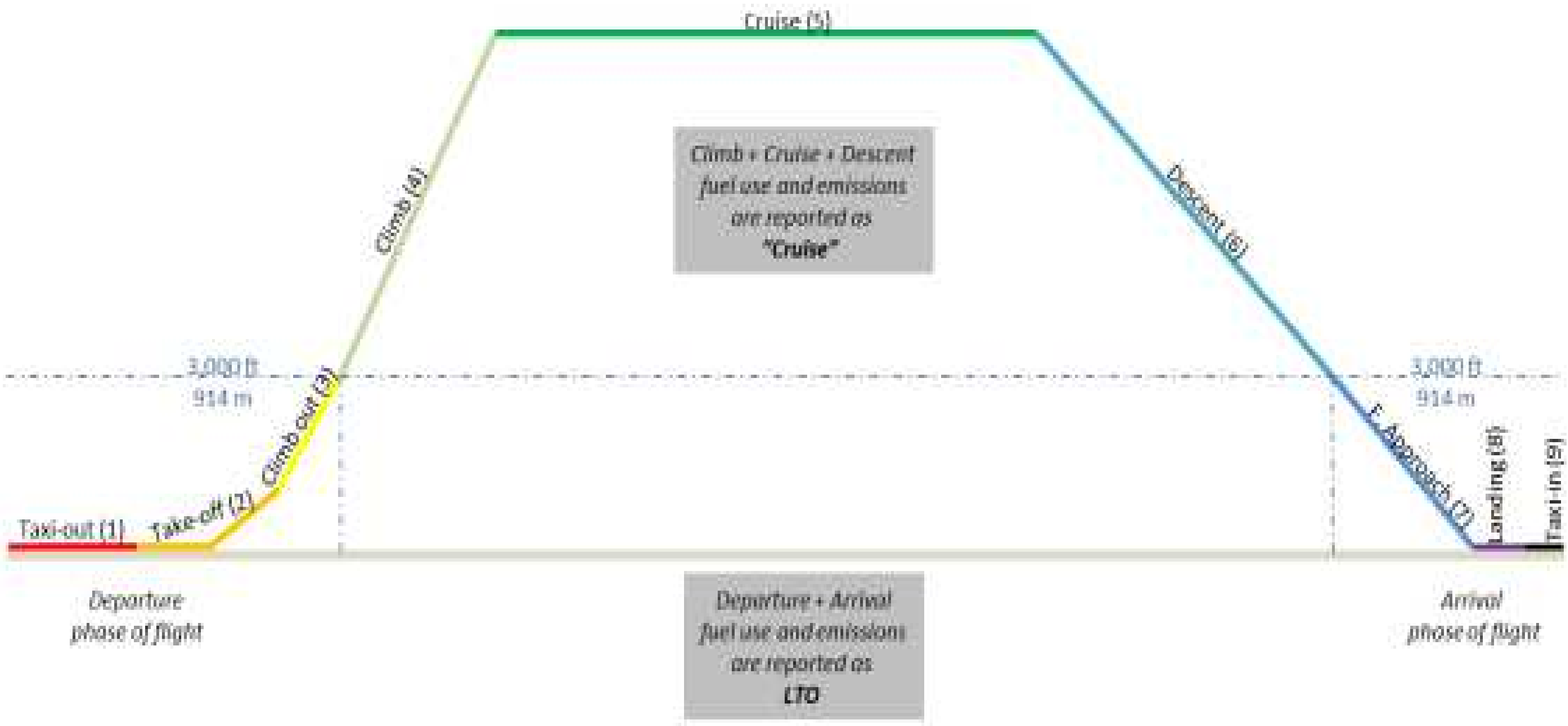
Figure 2.6 Contribution from aviation to the combustion emissions from mobile sources



Energy consumption….MJ/pkm

EMEP/EEA air pollutant emission inventory guidebook

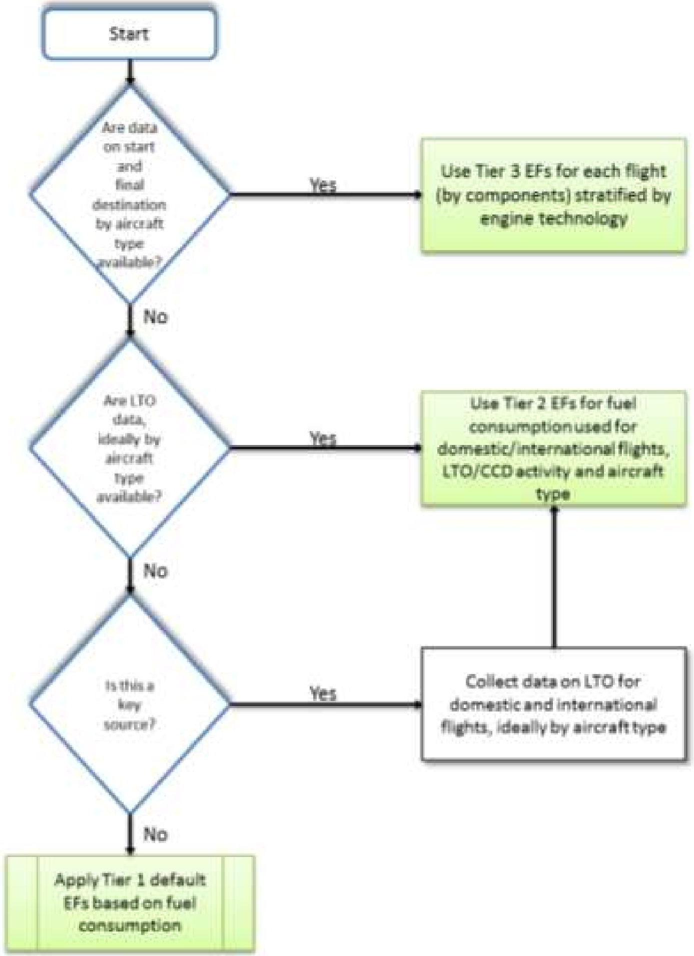
Figure 2.5 Aviation inventory activities versus the typical phases of a flight



Source: EUROCONTROL

Air transport

Figure 3.1 Decision tree for determining the appropriate tier method to apply



Note: EF – emission factor.

Energy consumption….MJ/pkm

EMEP/EEA air pollutant emission inventory guidebook (prior CORINAIR)

Total emissions = LTO emissions +cruise emissions

Table 3-5 Examples of aircraft types and emission factors for LTO cycles as well as fuel consumption per aircraft type, kg/LTO

Aircraft Icao	Engine Id	# of engines	Engine name	CO_2_kg	NO_x_kg	CO_kg	HC_kg	H_2O_kg	Pm_{25}_kg	BurntFuel_kg
A306	1PW048	2	PW4158	5427.9	25.9	14.8	1.2	2119.5	0.1	1723.1
A310	1GE015	2	CF6-80C2A2	4745.8	19.5	28.7	6.5	1853.1	0.1	1506.6
A319	3CM027	2	CFM56-5B5/P	2169.8	7.5	9.5	2.0	847.2	0.1	688.8
A320	1IA003	2	V2527-A5	2750.7	10.8	5.5	0.1	1074.1	0.1	873.3

Table 3–3 Emission factors and fuel use for the *Tier 1* methodology using jet kerosene as fuel. Emission factors are given on a representative aircraft basis

Tier 1 emission factors									
Domestic	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NMVOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) — average fleet (B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
LTO (kg/LTO) — old fleet (B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1	0.10
Cruise (kg/tonne) — average fleet (B737-400)	-	1.0	3150	2.0	10.3	0.1	0	0.1	0.20
Cruise (kg/tonne) — old fleet (B737-100)	-	1.0	3150	2.0	9.4	0.8	0	0.1	0.20
International	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NMVOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) — average fleet (B767)	1617	1.6	5094	6.1	26.0	0.2	0.0	0.2	0.15

Exercise

P#4 Find the CO_2 NOx and PM2.5 of a fleet of TAP aircraft for the Lisbon – Porto-Lisbon rides.

Exercise

CO_2, NO_x and PM2.5?

A320-214	190 nautic miles Max weight 16600 ton Fuel 1657 kg (Lisbon-Porto) jet fuel (35.2 MJ/l) 162 passengers capacity engine efficiency: 0.25 Vaverage=200 km/h 5 roundtrip flights

Exercise

CO_2?

5 roundtrip flights → **5*2*1657 = 16 570 kg jet fuel/day**

CnH2n

$$C_xH_yO_z + n(0.21O_2 + 0.79N_2) \rightarrow xCO_2 + yH_2O + 0.79 * nN_2$$

CO_2 [g/L$_{combustível}$] = $\frac{44*x}{12x+y+16z} * \rho$

gfuel/Lfuel

kgCO_2/kgfuel
=44n/(12n+2n)
=3.14

5 roundtrip flights → **5*2*1657 *3.14= 52 ton CO_2/day** → **19 000 ton CO_2/year**

Exercise

1.A.3.a, 1.A.5.b Aviation

Table 3.4 Examples of aircraft types and emission values for LTO cycles as well as fuel consumption per aircraft type, in kg/LTO

Aircraft type designator	Engine type (UID)	No of engines	CO_2 (kg)	NO_x (kg)	CO (kg)	HC (kg)	H_2O (kg)	$PM_{2.5}$ (kg)	Fuel burnt (kg)
A306	1PW048	2	5 427.9	25.9	14.8	1.2	2 119.5	1.2	1 723.1
A310	2GE037*	2	4 821.2	0.2	13.9	1.2	1 882.6	1.2	1 530.6
A319	3CM027	2	2 169.8	0.1	9.5	2.0	847.2	2.0	688.8
A320	3CM026*	2	2 570.9	0.1	8.2	1.6	1 003.9	1.6	816.2
A332	14RR071*	2	6 829.4	0.4	21.2	2.1	2 666.7	2.1	2 168.1
A333	14RR071*	2	6 829.4	0.4	21.2	2.1	2 666.7	2.1	2 168.1
A343	2CM015	4	6 362.6	0.4	25.2	3.9	2 484.5	3.9	2 019.9
A345	8RR044*	4	10 329.2	0.6	15.9	0.2	4 033.3	0.2	3 279.1

Exercise

Table 3–3 Emission factors and fuel use for the *Tier 1* methodology using jet kerosene as fuel. Emission factors are given on a representative aircraft basis

Tier 1 emission factors									
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LTO (kg/LTO) — average fleet (B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
LTO (kg/LTO) — old fleet (B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1	0.10
Cruise (kg/tonne) — average fleet (B737-400)	-	1.0	3150	2.0	10.3	0.1	0	0.1	0.20
Cruise (kg/tonne) — old fleet (B737-100)	-	1.0	3150	2.0	9.4	0.8	0	0.1	0.20
International	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NMVOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) — average fleet (B767)	1617	1.6	5094	6.1	26.0	0.2	0.0	0.2	0.15

Exercise

Total emissions per aircraft = LTO emissions + cruise emissions

816.2 kg jet fuel

NO_x = 0.1 kg
PM2.5 = 1.6 kg

1657 – 816.2 = 840.8 kg jet fuel

NO_x = 10.3 kg/tonjet*0.8408 tonjet = 8.660 kg
PM2.5 = 0.2 kg/tonjet*0.8408 tonjet = 0.168 kg

5 roundtrip flights →

NO_x = 10* (0.1 kg+8.660 kg) = 87.6 kg/day
PM2.5 = 10*(1.6 kg+0.168 kg) = 17.7 kg/day

5 roundtrip flights →

32 ton NO_x/year

6.5 ton PM2.5/year

Thanks

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