Ciências
ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa

DISCIPLINA MIEA 2018

Mobilidade Sustentável

Energy and emissions

Home ⟷ Work/ University

on a regular basis

Commuting by motorized or soft modes

Emissions

Energy

Autonomous....

Autonomous driving

Inter-terminal Gatwick airport 2008

Autonomous driving

Barcelona Metro line 9 without train driver 2009

Autonomous driving

Heathrow Personal Rapid Transit system 2011

18 low-energy, driverless vehicles can each carry four passengers and their luggage. (Ultra PRT | www.ultraprt.com.)

Autonomous driving

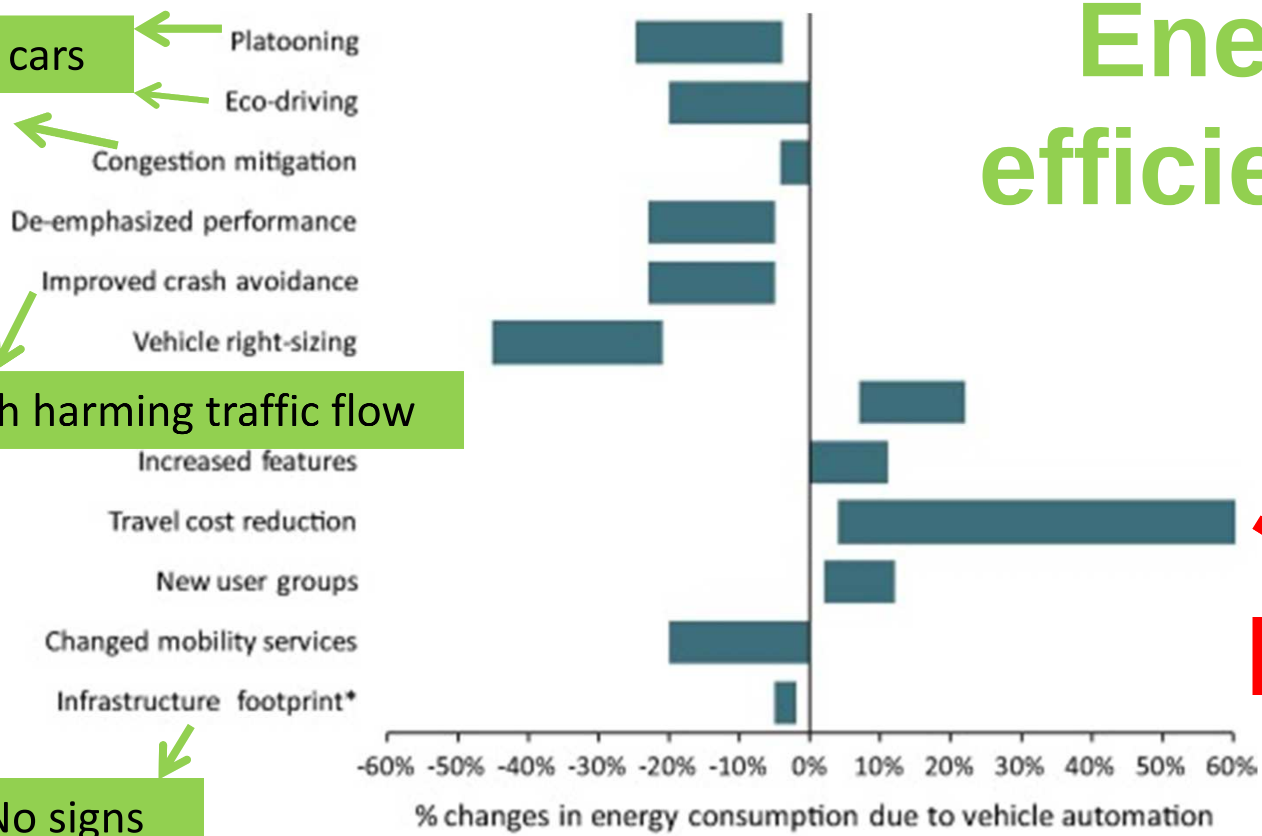
- **Autonomous vehicles**

Washinton D.C. 2016

Self-driving cars and energy consumption

Energy efficiency?

Train of cars



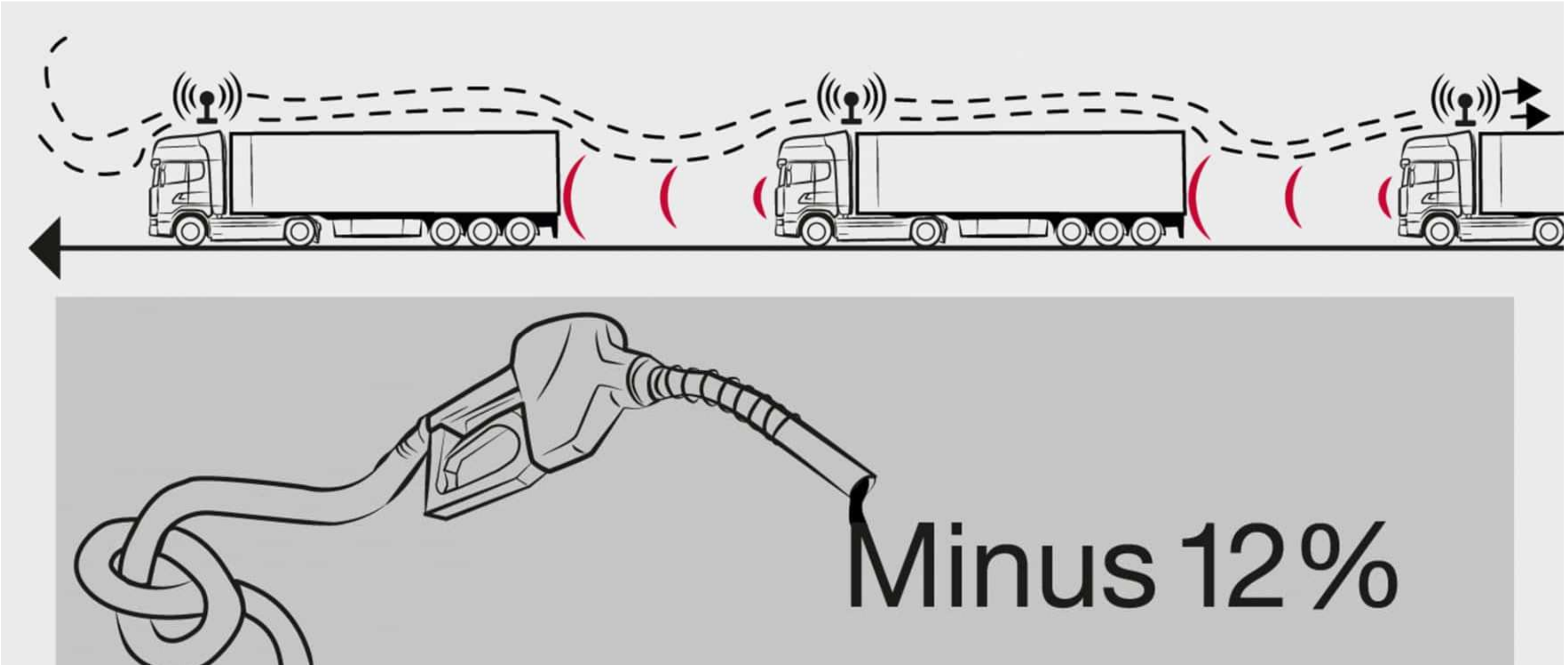
No crash harming traffic flow

No signs

Rebound effect

@ Help or hindrance? The travel, energy and carbon impact of highly automated vehicles Article · Apr 2016 · Transportation Research Part A Policy and Practice

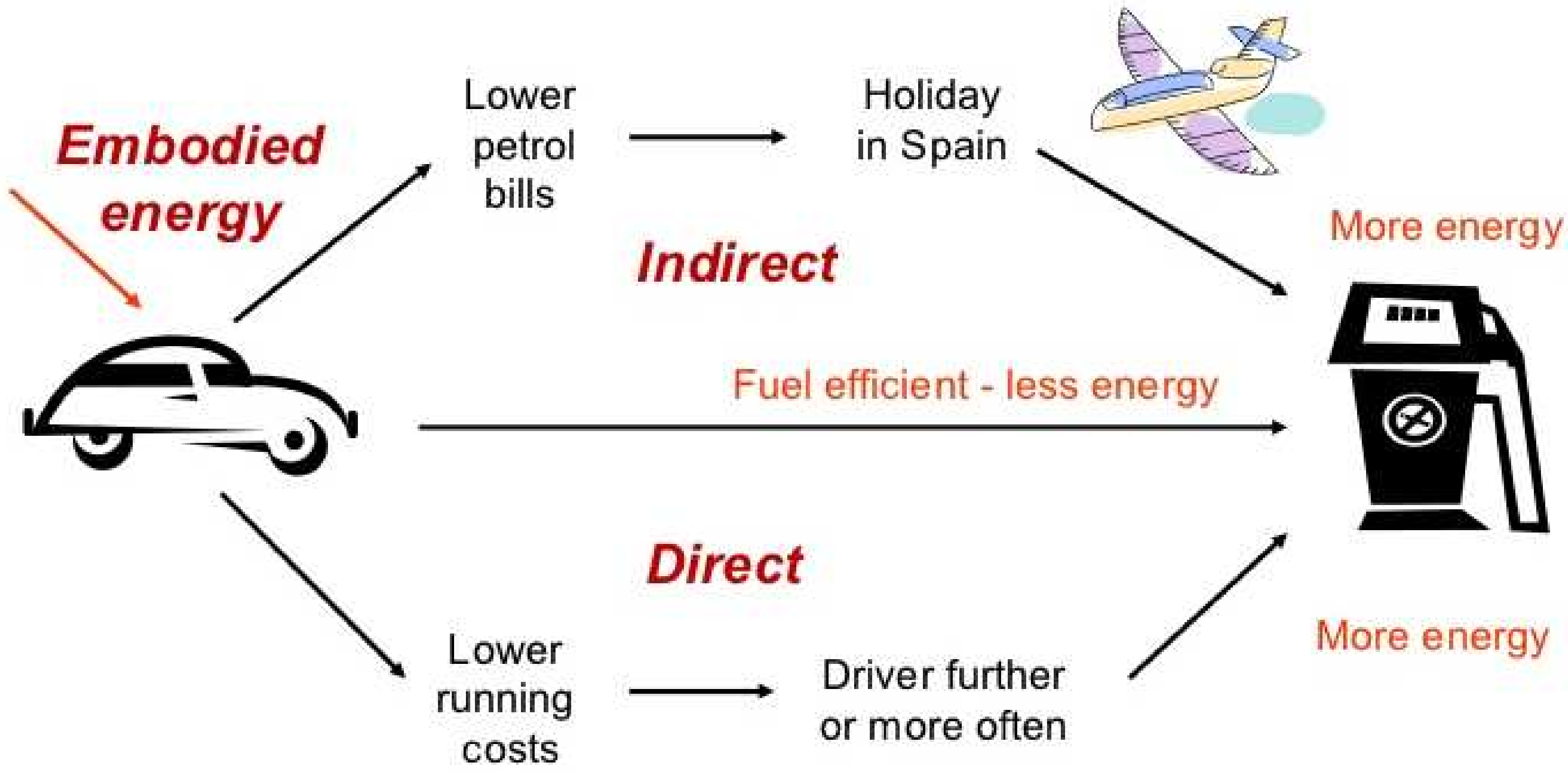
Transport.....energy



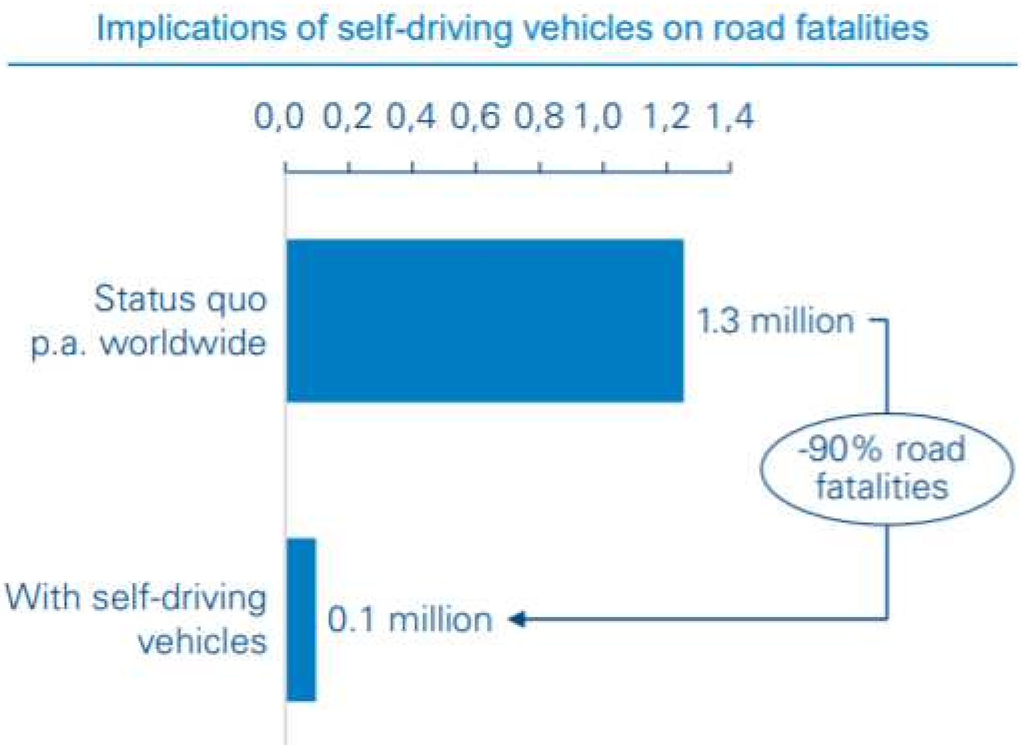
@ https://www.scania.com/group/en/platooning-saves-up-to-12-percent-fuel/

Transport…..energy

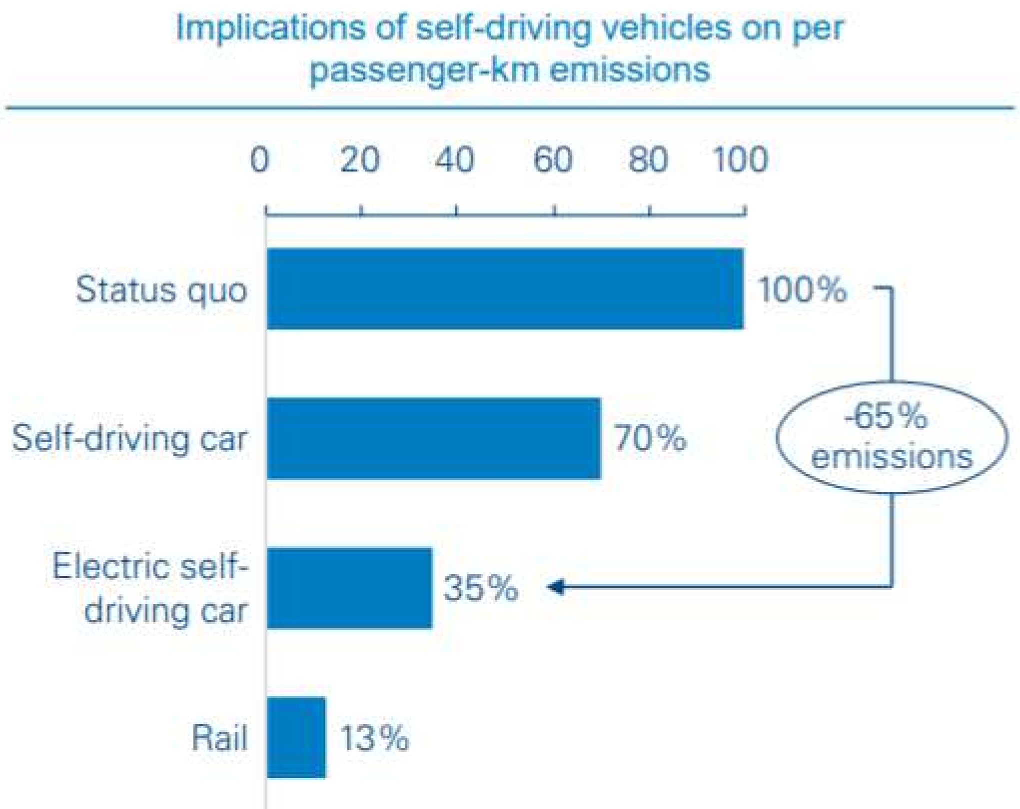
The rebound effect in plain terms is the misconception that using energy-efficient technology significantly cuts energy consumption and greenhouse gas emissions



Energy and emissions



Energy and emissions



Energy and emissions

Criteria	Weight	Definition
19 Transport-related CO_2 emissions	4	■ Ratio between the total amount of carbon dioxide emitted by the agglomeration area p.a. as a consequence of its transport activities and its population ■ The data considers carbon dioxide emissions from the burning of fossil fuels in transportation only (sectorial approach)
20 NO_2 concentration	4	■ Annual arithmetic average of the daily concentrations of NO2 recorded at all monitoring stations within the agglomeration area
21 PM_{10} concentration	4	■ Annual mean concentration of particulate matter of less than 10 microns of diameter (PM10) [ug/m3] in a city/ agglomeration area ■ For most of cities data from the WHO Global Urban Ambient Air Pollution Database was used (update 2016). Other sources if the city was not available in the WHO Database
22 $PM_{2.5}$ concentration	4	■ Annual mean concentration of particulate matter of less than 2.5 microns of diameter (PM2.5) [ug/m3] in a city/ agglomeration area ■ For most cities data from the WHO Global Urban Ambient Air Pollution Database was used (update 2016). Other sources if the city was not available in the WHO Database

Minimum and maximum values of indicator scale (maximum 16 points out of 100 for CO2, NO2, PM10 and PM2.5)

e.g. PM10 150 / 10 (μg/m3)

0 – 4

e.g. CO_2 kg/capita/year 7.5- 0

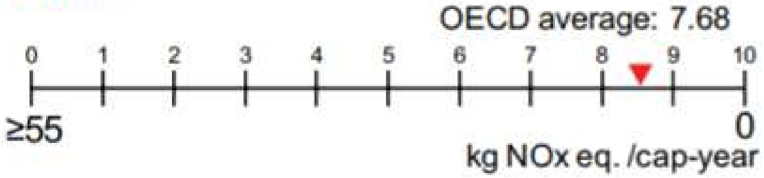
Energy and emissions

wbcsd

Pollutant	Relative importance (based on 2007USD) with NOx, cost as reference
NO_x	1.00
PM_{10}	1.06

(**Source:** AEA Technology (2005) and Wang, Santini & Warinner (1994), US cities as in Victoria Transport Policy Institute (2011), www.vtpi.org).

f Scale



➔ 0: ≥55 [kg NOx eq./ cap-year]
➔ 10: 0 [kg NOx eq./ cap-year]

Energy and emissions

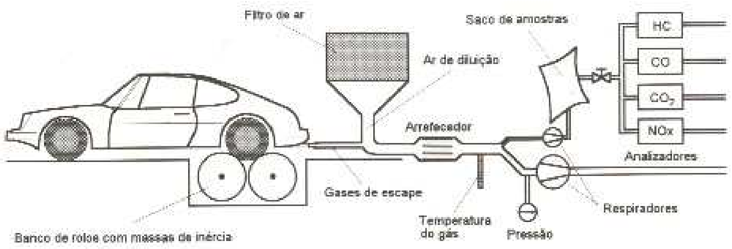
LOCAL AIR QUALITY EMISSIONS (EUROPE)

					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.

Energy and emissions



EU

g/km not g/m^3

Índia

China

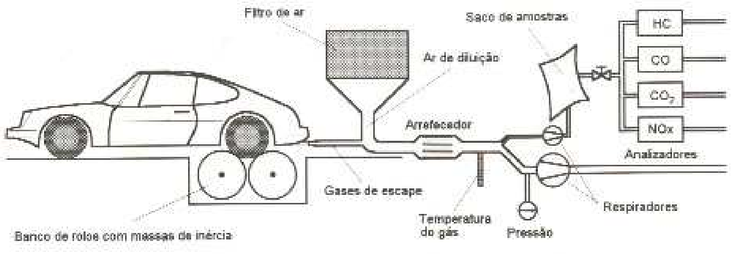
Turkey

Russia

Switzerland

Thailand

Energy and emissions



g/km

Premium

CERC - Version ADMS-Urban - Air Pollution Modelling Software

ADMS-Urban is a comprehensive system for modelling air quality in large urban areas, cities and towns. It is the only practical urban air quality model which incorporates the latest scientific understanding, explicitly represents the full range of source types occurring in an urban area, takes account of complex urban morphology including ...

By Cambridge Environmental Research Consultants (CERC) based in **Cambridge, UNITED KINGDOM**.
from Air Pollution Modelling Software
Software line

g/m^3

Why do we have emissions???

Products of ideal combustion

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

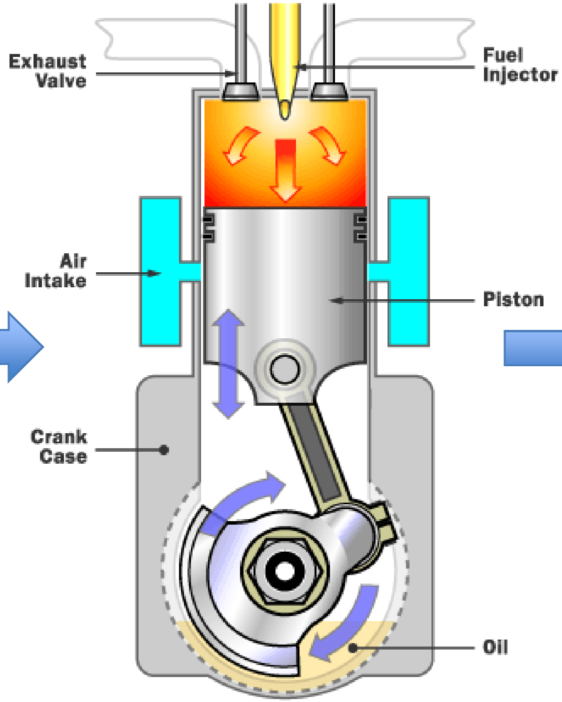
Fuel (C_nH_m) Air ($N_2 + O_2$)

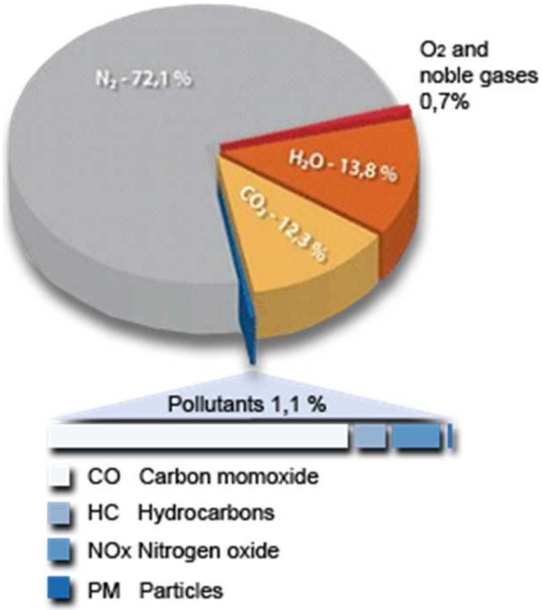
$+ NH_3$

Products of non-ideal combustion

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

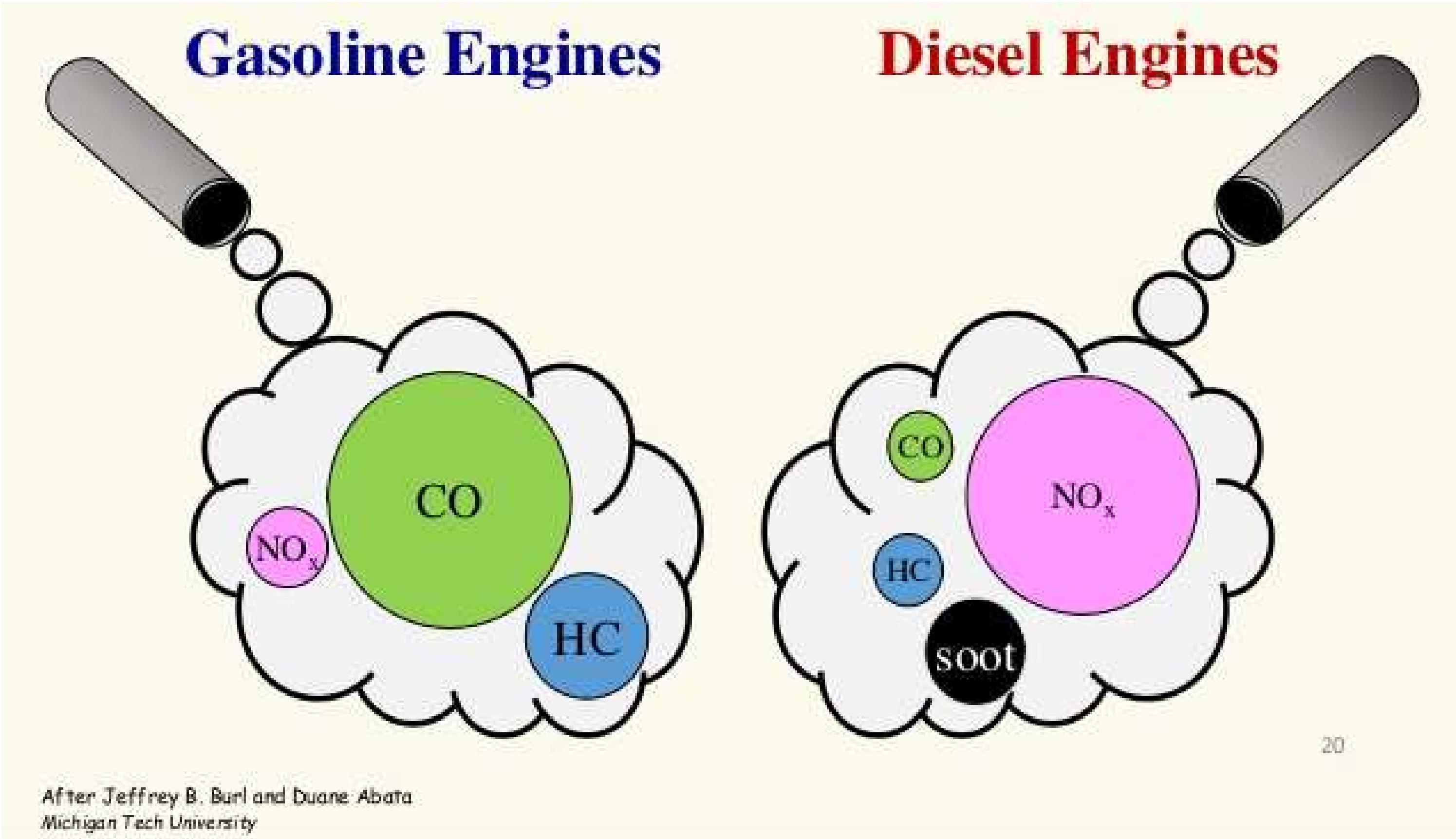
Why do we have emissions???



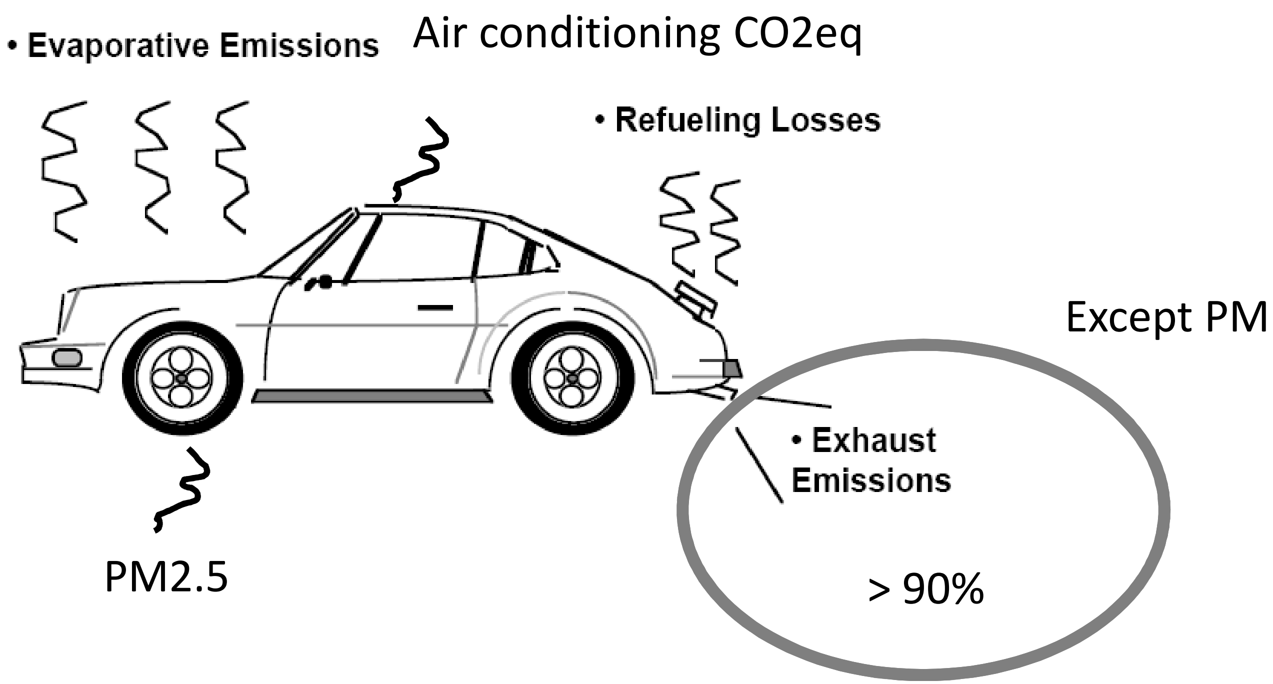


MOBILE COMBUSTION

LOCAL EMISSIONS



Emissions

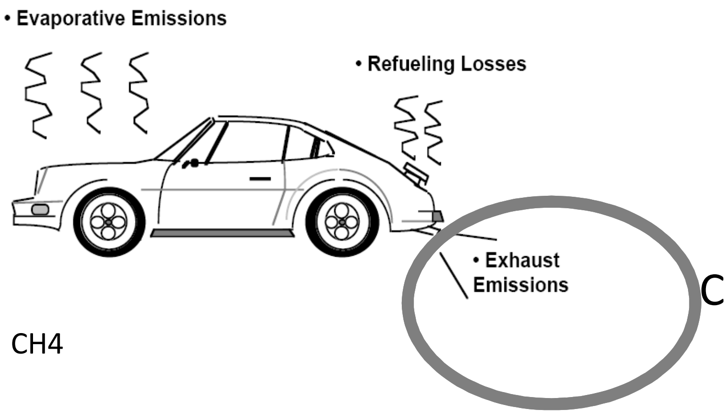


MOBILE COMBUSTION

Emissions

Global

CO_2



Tailpipe

CH4, N2O ~ 0.3-3% of tailpipe CO2

CO_2, N2O, CH4

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.

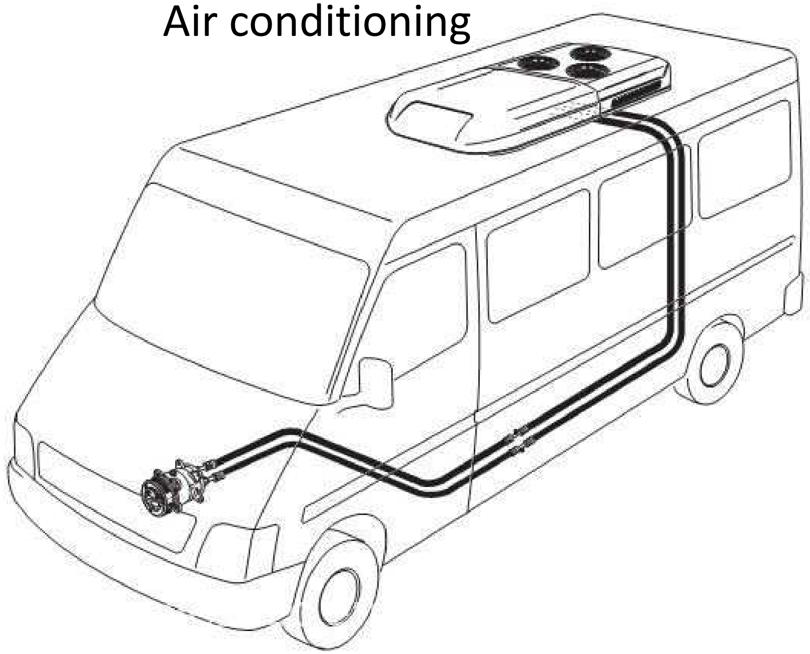
Emissions

Global

CO_2 equivalent

Air conditioning

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



Refrigerant : R-134a.
Refrigerant charge : 1800 ± 100 gr.
Oil : SP-20.
Oil charge : 110 cc (In addition to the existing oil in the compressor).

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

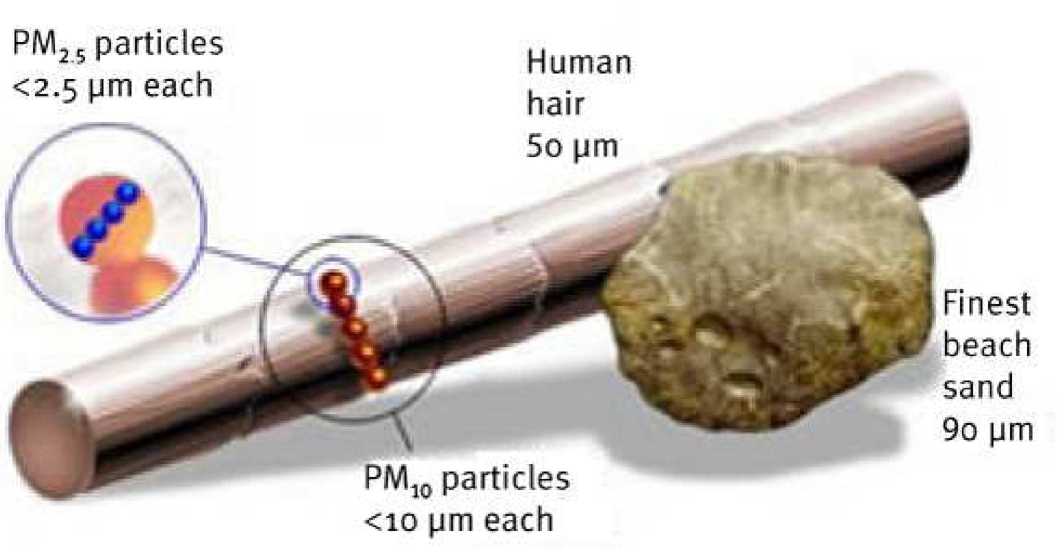
CO_2 equivalent

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

Intergovernmental Panel on Climate Change (IPCC)

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	RadiativeEfficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]$1.4x10^{-5}$	1	1	1	1
Methane[c]	CH_4	12[c]	$3.7x10^{-4}$	21	72	25	7.6
Nitrous oxide	N_2O	114	$3.03x10^{-3}$	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

PM2.5 and PM10



Emissions

primary emissions of PM2.5

1) it is directly emitted from the tailpipes of cars, trucks and other on-road vehicles;

2) it is re-entrained from materials found on the roadway (typically known as fugitive dust), and

3) it is created by secondary formation from precursor emissions such as sulfur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and ammonia (NH_3).

30% to 90% of all PM2.5

Source: https://www3.epa.gov/ttnchie1/conference/ei13/mobile/hodan.pdf

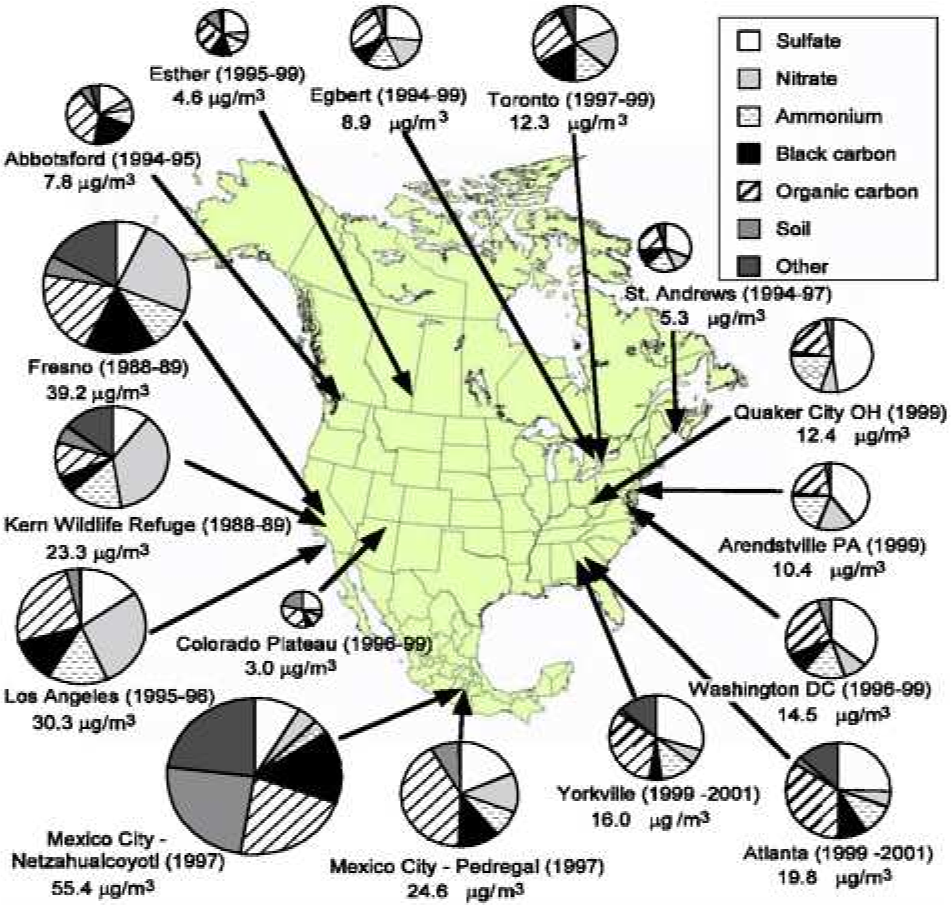
LOCAL EMISSIONS

2)

- paved roads contributes between 3% and 16% of total directly emitted PM2.5, and

- unpaved roads contribute between 9% and 22% of total directly emitted PM2.5

PM2.5 and PM10



Minerals (Fe, Ca, Si)

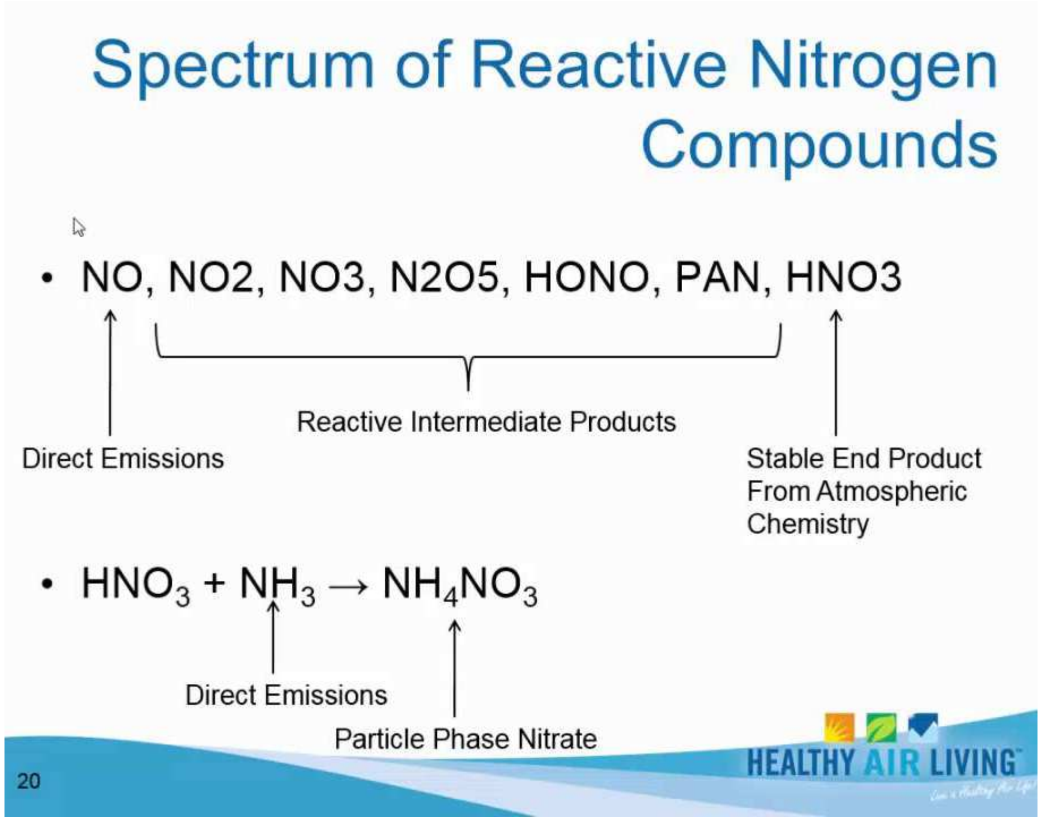
Sulfates ($SO4^{2-}$)

Nitrates ($NH4^{+}$)

Organic carbon

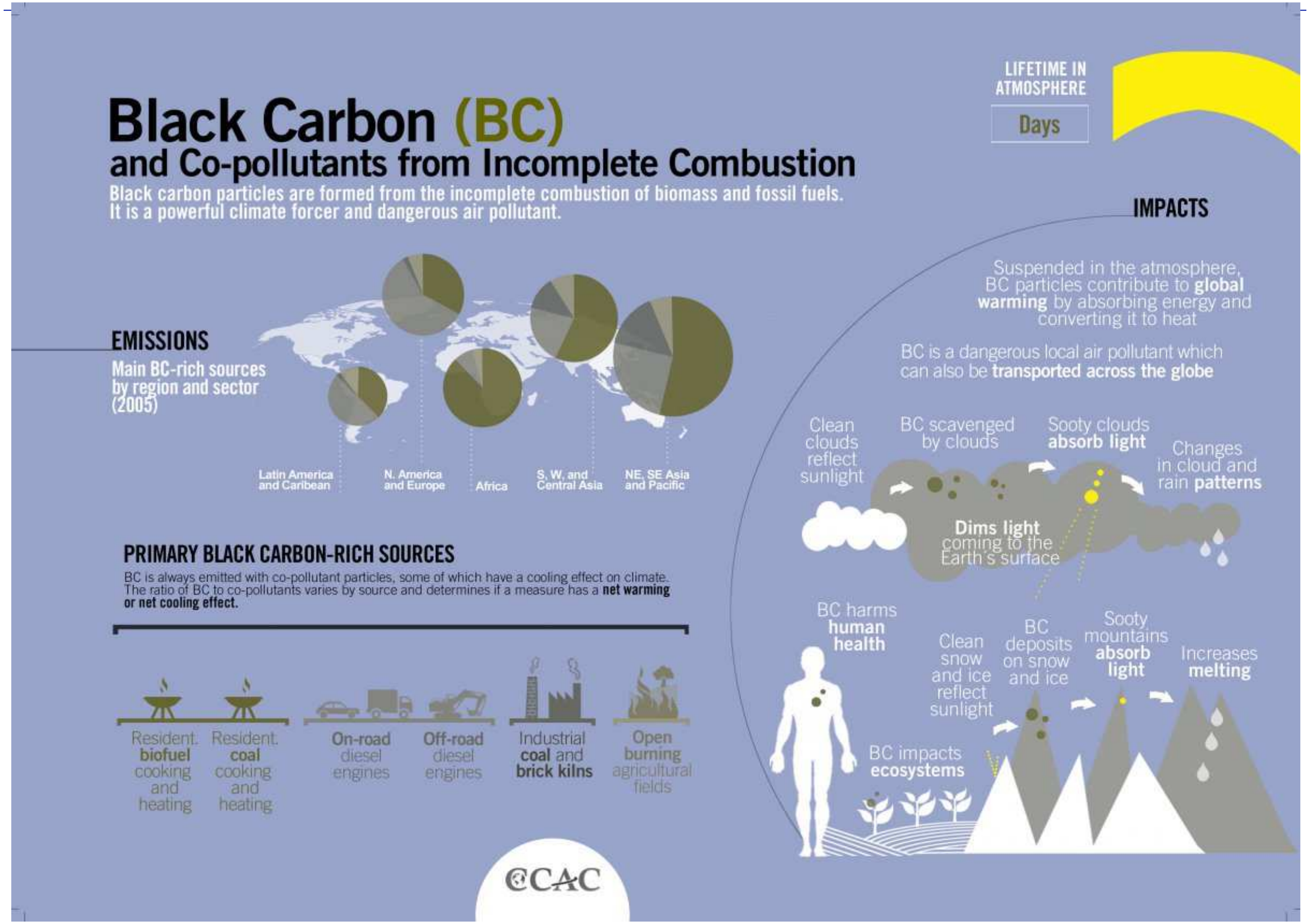
Elemental carbon

PM2.5 and PM10



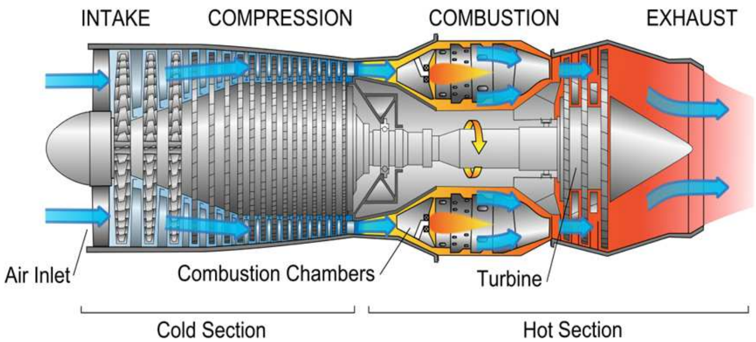
Nitrates ($NH4^+$)

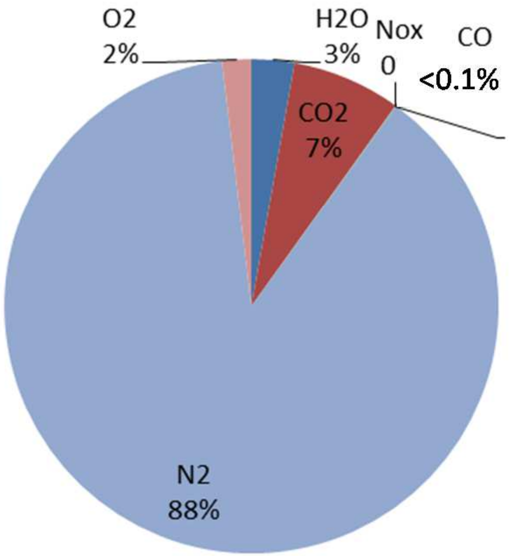
LOCAL EMISSIONS

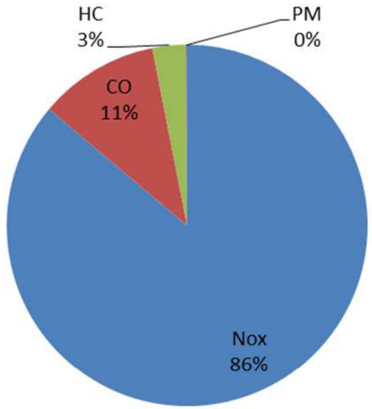


Emissions

Why do we have emissions???







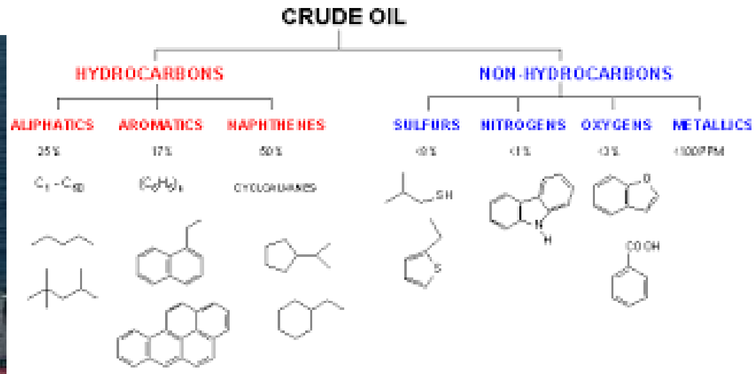
MOBILE COMBUSTION

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/m^3)	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
Hydrogen	(35 MPa)	23.65 ± 0.09	1.183 ± 0.001	2.837 ± 0.003	119.95 ± 0.13	3.355 ± 0.004	141.88 ± 0.16	0
	(70 MPa)	39.69 ± 0.16		4.761 ± 0.005		5.631 ± 0.006		
	(liquid)	72.41 ± 0.72		8.685 ± 0.010		10.273 ± 0.011		
		(kg/m^3)	(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/m^3)	(HHV / LHV)	(MJ/m^3)	(MJ/kg)	(MJ/m^3)	(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

Local

HC, CO, NOx and PM

Global

CO_2 equivalent or GHG

Local

4.2 million

deaths every year as a result of exposure to ambient (outdoor) air pollution

3.8 million

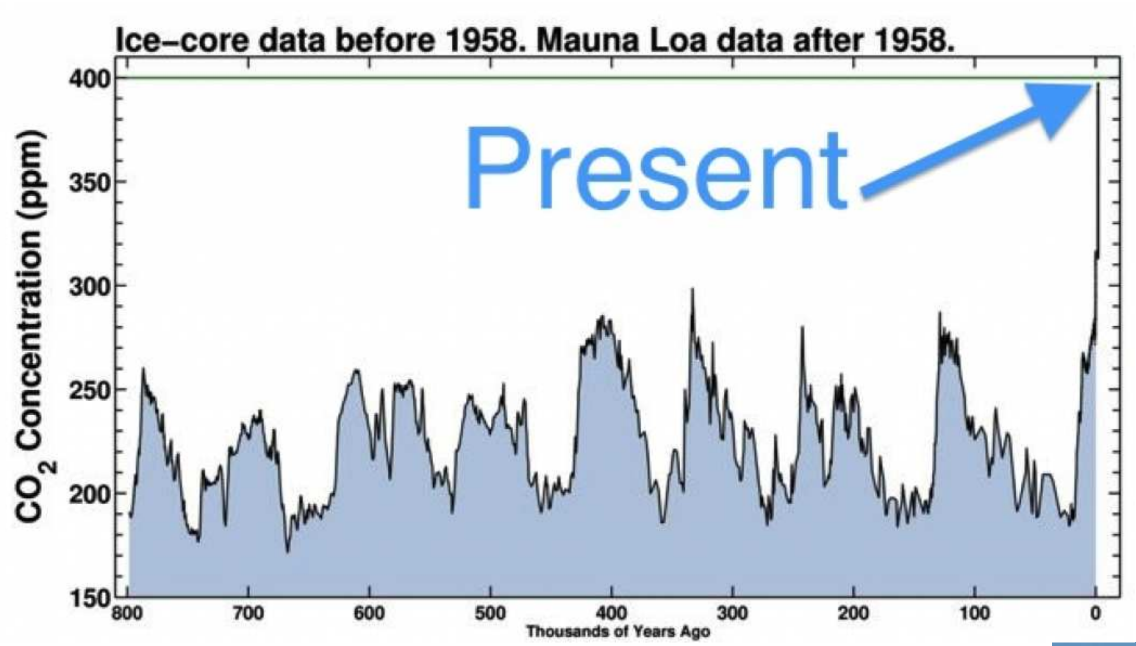
deaths every year as a result of household exposure to smoke from dirty cookstoves and fuels

91%

of the world's population lives in places where air quality exceeds WHO guideline limits

World Health Organization

Emissions



400 ppm CO_2 in outdoor environment

Global

CO_2 equivalent or GHG

Emissions

400 ppm CO_2 in outdoor environment

pV=nRT

PTN = Standard pressure and Temperature

Pressure = 100 kPa
Temperature = 298 K

0.7 g/m³ CO_2 in outdoor environment

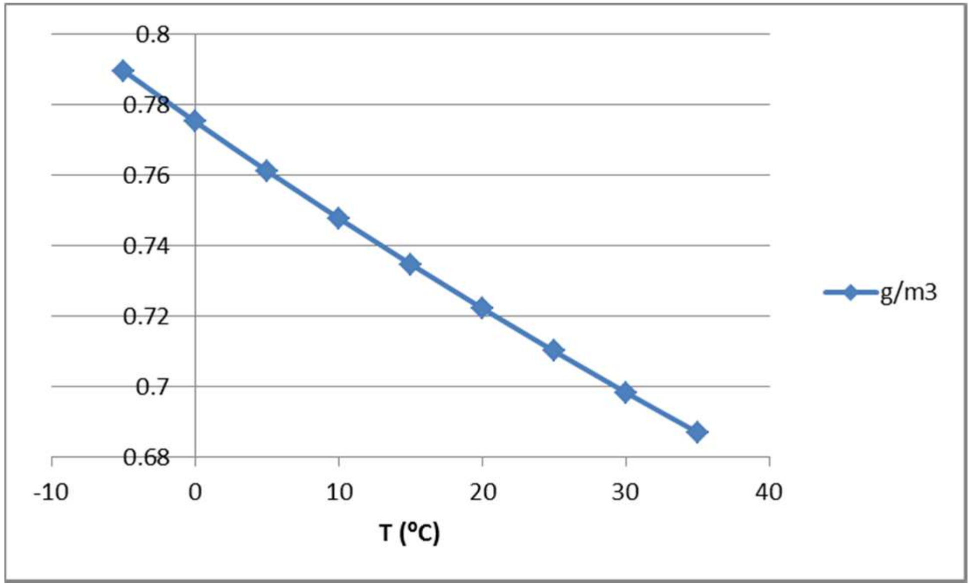
Emissions

400 ppm CO_2 in outdoor environment

$$\frac{400 * 10^{-6}\, kmol\ CO_2}{1\ kmol\ air} * \frac{(12 + 2 * 16) kg/kmolCO_2}{\frac{8.314 \frac{kJ}{kmolair.K} * 298K}{100kPa}}$$

0.7 g/m³ CO_2 in outdoor environment

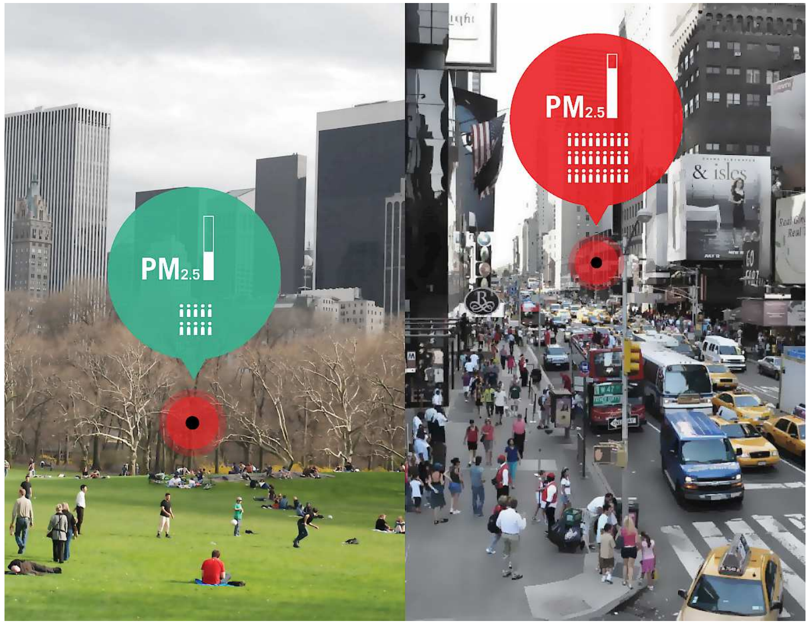
Effect of temperature in real conditions…..



LOCAL EMISSIONS

Partícle (PM)

PM_{10} daily average <= 50 µg/m_3
PM_{10} anual average <= 40 µg/m_3.
$PM_{2.5}$ annual average <= 25 µg/m3.



Óxidos de azoto (NOx)< 30 µg/m^3
Média anual

Óxidos de azoto (NO2)< 200 µg/m3
1 hora

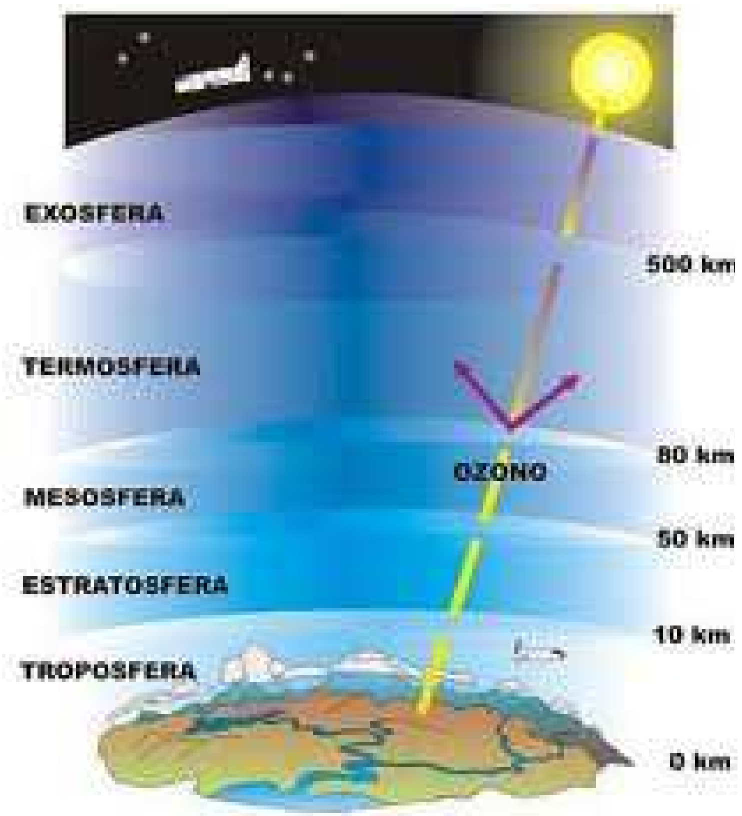
Monóxido de carbono (CO) < 10 mg/m^3
Média máxima por períodos de 8 horas

Benzeno (C_6H_6) < 5 µg/m3
Média anual

Dióxido de Enxofre (SO_2) < 500 µg/m3
1 hora

Ozono (O3) < 240 µg/m^3
1 hora

Tropospheric ozone O3 and smog Overview: Tropospheric ozone, smog and ozone-NOx-VOC sensitivity. Dr. Sanford Sillman, Research Scientist,University of Michigan



$$VOC + OH \overset{[O_2]}{\rightarrow} RO_2 + H_2O \qquad R1$$

$$CO + OH \overset{[O_2]}{\rightarrow} HO_2 + CO_2 \qquad R2$$

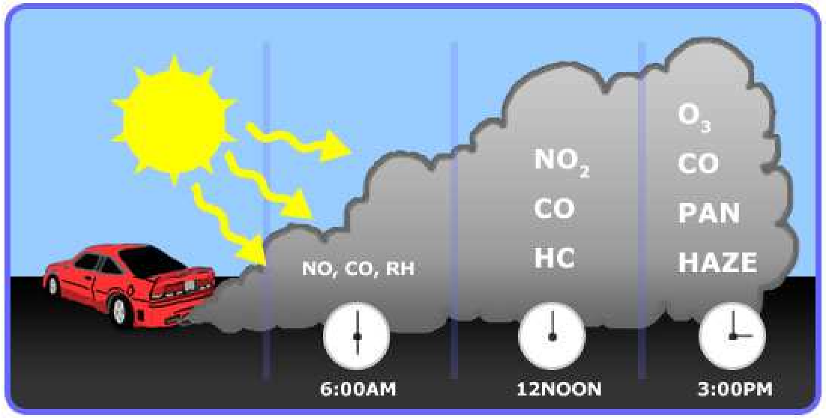
$$RO_2 + NO \overset{[O_2]}{\rightarrow} \text{secondary } VOC + HO_2 + NO_2 \qquad R3$$

$$HO_2 + NO \rightarrow OH + NO_2 \qquad R4$$

$$NO_2 + h\nu \rightarrow NO + O \qquad R5$$

$$O + O_2 + M \rightarrow O_3 + M \qquad R6$$

LOCAL EMISSIONS



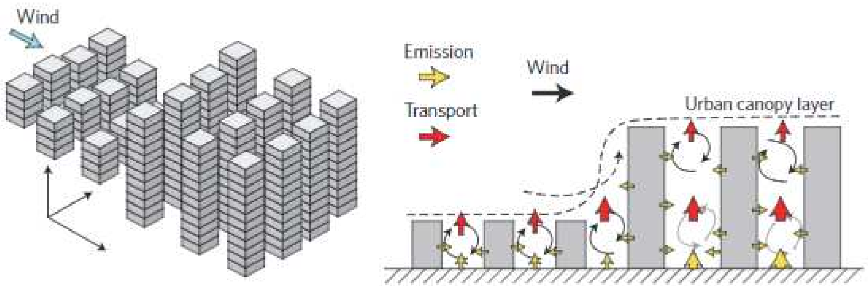


Figure 1 | Schematic illustration of air flow, pollutant concentration and dispersion with different building heights.

@ Air quality by urban design de Y Zhang - 2013

MONITORING NEEDED TO ADVISE PEOPLE!

e.g. colour scheme

Hazardous

O_3 (ppb)	O_3 (ppb)	$PM_{2.5}$($\mu g/m^3$)	PM_{10}($\mu g/m^3$)	CO (ppm)	SO_2 (ppb)	NO_2 (ppb)	AQI	AQI
C_{low} - C_{high}(avg)	C_{low} - C_{high}(avg)	C_{low}- C_{high}(avg)	C_{low} - C_{high}(avg)	C_{low} - C_{high}(avg)	C_{low} - C_{high}(avg)	C_{low} - C_{high}(avg)	I_{low} - I_{high}	**Category**
0-54 (8-hr)	-	0.0-12.0 (24-hr)	0-54 (24-hr)	0.0-4.4 (8-hr)	0-35 (1-hr)	0-53 (1-hr)	0-50	Good
55-70 (8-hr)	-	12.1-35.4 (24-hr)	55-154 (24-hr)	4.5-9.4 (8-hr)	36-75 (1-hr)	54-100 (1-hr)	51-100	Moderate
71-85 (8-hr)	125-164 (1-hr)	35.5-55.4 (24-hr)	155-254 (24-hr)	9.5-12.4 (8-hr)	76-185 (1-hr)	101-360 (1-hr)	101-150	Unhealthy for Sensitive Groups
86-105 (8-hr)	165-204 (1-hr)	55.5-150.4 (24-hr)	255-354 (24-hr)	12.5-15.4 (8-hr)	186-304 (1-hr)	361-649 (1-hr)	151-200	Unhealthy
106-200 (8-hr)	205-404 (1-hr)	150.5-250.4 (24-hr)	355-424 (24-hr)	15.5-30.4 (8-hr)	305-604 (24-hr)	650-1249 (1-hr)	201-300	Very Unhealthy
-	405-504 (1-hr)	250.5-350.4 (24-hr)	425-504 (24-hr)	30.5-40.4 (8-hr)	605-804 (24-hr)	1250-1649 (1-hr)	301-400	Hazardous
-	505-604 (1-hr)	350.5-500.4 (24-hr)	505-604 (24-hr)	40.5-50.4 (8-hr)	805-1004 (24-hr)	1650-2049 (1-hr)	401-500	

USEPA AQI (https://waqi.info/)

CAQI (http://airindex.eea.europa.eu/)

Pollutant	**Index level** (based on pollutant concentrations in μg/m3)				
	Good	**Fair**	**Moderate**	**Poor**	**Very poor**
Particles less than 2.5 μm ($PM_{2.5}$)	0-10	10-20	20-25	25-50	50-800
Particles less than 10 μm (PM_{10})	0-20	20-35	35-50	50-100	100-1200
Nitrogen dioxide (NO_2)	0-40	40-100	100-200	200-400	400-1000
Ozone (O_3)	0-80	80-120	120-180	180-240	240-600
Sulphur dioxide (SO_2)	0-100	100-200	200-350	350-500	500-1250

Energy and emissions

MONITORING NEEDED TO ADVISE PEOPLE!

e.g. qualar (from APA-Agência Portuguesa do Ambiente)
https://qualar.apambiente.pt/qualar/index.php

e.g. World Air quality index
https://waqi.info/

World Health Organization

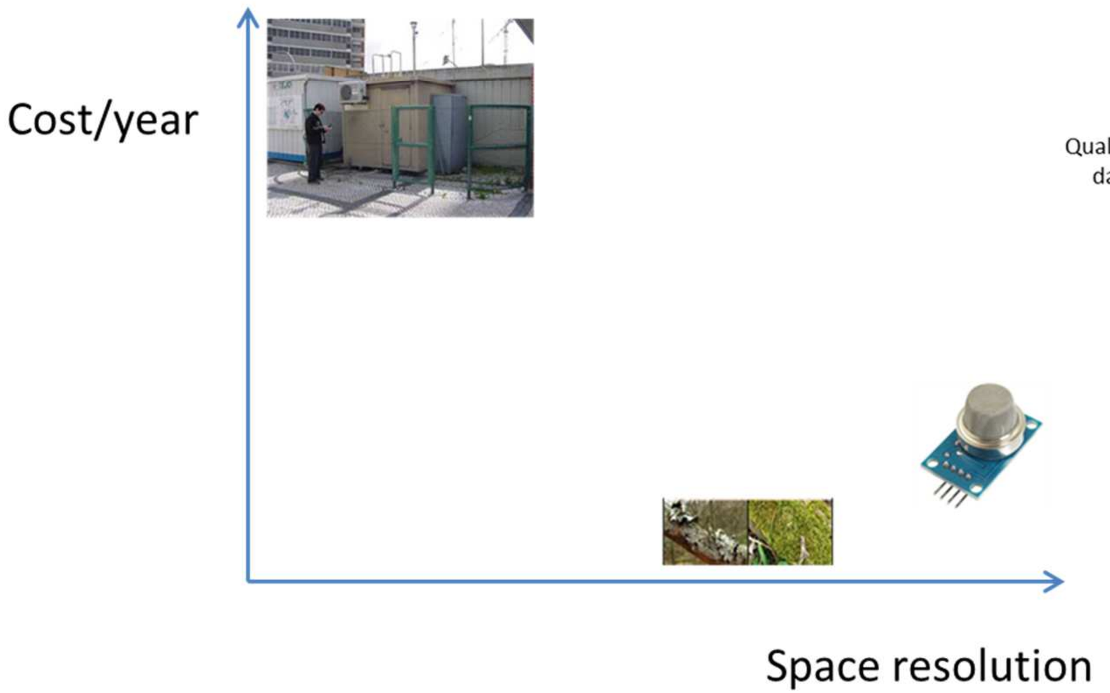
LIMITS!

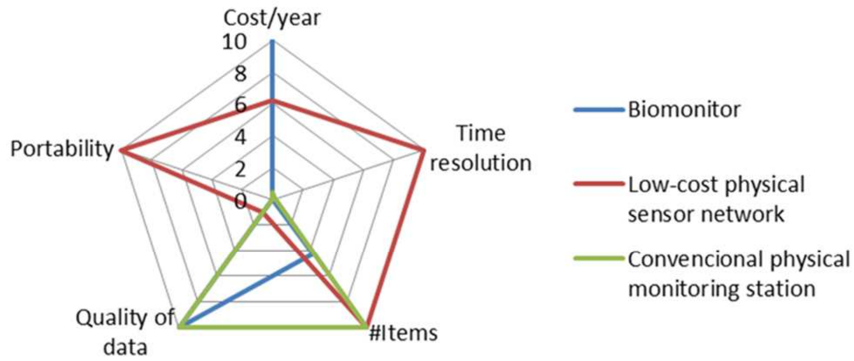
PM 2.5 exposure of 25 μg/m3

PM 2.5 exposure of 35 μg/m3

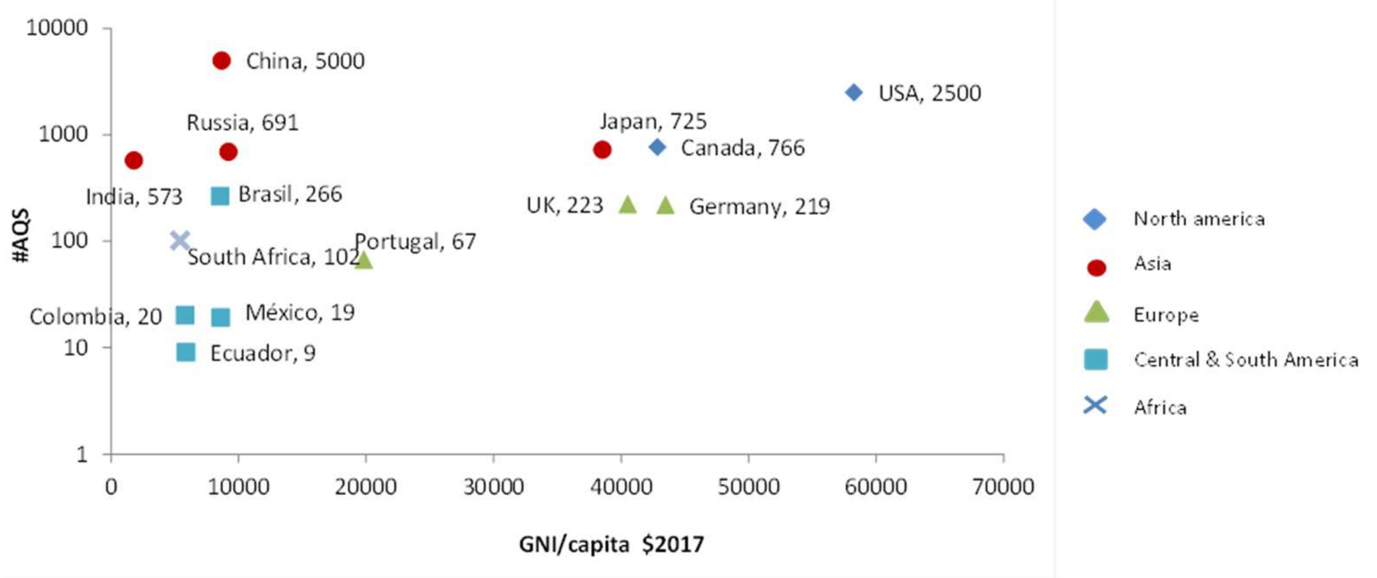
PM 2.5 exposure of 75 μg/m3

MONITORING NEEDED TO ADVISE PEOPLE!





MONITORING NEEDED TO ADVISE PEOPLE!



# AQS = number air quality monitoring stations
GNI = Gross National Income *

* is the total domestic and foreign output claimed by residents of a country, consisting of gross domestic product (GDP), plus factor incomes earned by foreign residents, minus income earned in the domestic economy by nonresidents

MONITORING NEEDED TO ADVISE PEOPLE!

Equipamento	Referência	Custo	Peso (kg)	âmbito	Portabilidade
	https://www.airpointer.com/	*High-Cost* 120 000€	80	Estação oficial compacta de qualiade do ar	
	https://www.qart.pt/solutions/qart-box/	*Medium-Cost 4 000€*	3 kg	Ruído, PM2.5, O3, NOx,SO2, H2S	
	http://aqicn.org/gaia/	*Low-Cost 200 €*	3 kg	PM2.5 e O3	

MONITORING NEEDED TO ADVISE PEOPLE!

	**FCUL** (Augusto, Máguas, Matos, Pereira, & Branquinho, 2010)	*Low-Cost 500 €/análise*	NA	Sensor biológco correlacionável com partículas, VOC, NOx	
	Rede de 6 sensores em escolas (Castell et al., 2018) da Aqmesh (https://www.aqmesh.com)	*Low-Cost ~200 €*	NA	CO, NO, NO_2 and O_3	
	Rede de 3 sensores numa estrada (Khedo, Perseedoss, & Mungur, 2010)	*Low-Cost ~200 €*	3 kg	CO, NO_2, PM2.5, O_3	

You learned....

- Pollutants concentration and health;
- ppm conversion to g/m^3;
- Portuguese “Qualar” website; World air quality map;
- Air quality monitors high; medium and low-cost;
- “Qart box” example for air quality monitoring.

Obrigado

Ciências ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa