How to Define Clean Vehicles? Environmental Impact Rating of Vehicles

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Introduction

- In urban areas
  - Pollution caused by transport is a heavy burden
  - Joint presence of large number of
    - Pollution sources (cars)
    - Receptors (people and buildings)
  - ExternE : project transport in the Brussels Capital Region : 774 M€ (Source : CEESE-ULB)
- Brussels ordinance “Air”
  - In coming 5 years
  - At least 20% of the vehicles of the public fleets
  - Must be ‘clean vehicles’
- “What are Clean Vehicles?”

Introduction

- Brussels capital region commissioned
- Via BIM-IBGE (Brussels institute for the conservation of the environment)
-
- ***“Clean vehicles” research project***

- Jointly carried by
  - Vrije Universiteit Brussel (ETEC)
  - Université Libre de Bruxelles (CEESE)

- Final report (500pg)

Overview

- Comparison alternative fuels and drive
- Methodology
  - Environmental damage rating
    - How should?
      ⇒ vehicle emissions
      ⇒ influence human being and environment
    - How could?
      ⇒ availability of (accurate & reliable) data
  - Ecoscore

Comparison (Belgian situation)

Feature	Gasoline	Diesel	LPG	Natural gas	Bio-diesel	Alcohol	EV	Hybrid E
ate of the art	EURO IV-norm Currently available		Broadly available	Limited availability	Not available at filling station		Limited availability of different types	Only 2 available models
ange	Ref.	Higher than gasoline	300 km (mono-fuel)	200 a 250 km (mono-fuel)	Mix		70 a 100 km	Higher than gasoline diesel
lling time	Some minutes			10 min. or 6-7 hour	Some minutes		15 min. or 5-8 hour	
afety	Strongly flammable	Carcino-genic, mutagenic and toxic	Original installation is comparable with gasoline	Comparable with gasoline	Biode-gradable	Highly toxic and corrosive	Safer than gasoline and diesel. Battery can be recycled	
vailable frastructure	Extended network available			Shortage of public filling stations	No public filling stations		Distribution network exists. Shortage of public filling stations. Socket.	

Comparison (Belgian situation)

Feature	Gasoline	Diesel	LPG	Natural gas	Bio-diesel	Alcohol	EV		Hybrid
st price	😐	☹	☹	☹☹	☹	😐	☹☹☹		☹☹
vernmental ervention	Yes, if EURO IV-norm is satisfied		Different for original and adapted systems	No	No	No	No		No
rect energy ns.	100%	70-90%	85-104%	80-125%	85-90%	105-125%	25-30%		Depend on the f
mary energy ns.	100%	70-90%	80-100%	80-115%	63-110%	105-120%	25-80%		50-90
issions:							E.P.E	.E.P.I.	
NOx	100%	150-900%	60-160%	35-100%	190-370%	30-90%	0%	15-40%	25-40
HC	100%	30-1000%	25-170%	10-230%	40-60%	85-230%	0%	1-23%	10-50
CO	100%	15-60%	15-80%	25-80%	20-80%	40-125%	0%	0-1%	10%
SO_2	100%	170-900%					0%	200%	
PM	100%	1000%	10-100%	5-10%	90-1000%	40%	0%	65-75%	
CO_2	100%	75-100%	80-100%	90-100%	40-110%	100-185%	0%	15 a 160%	60%

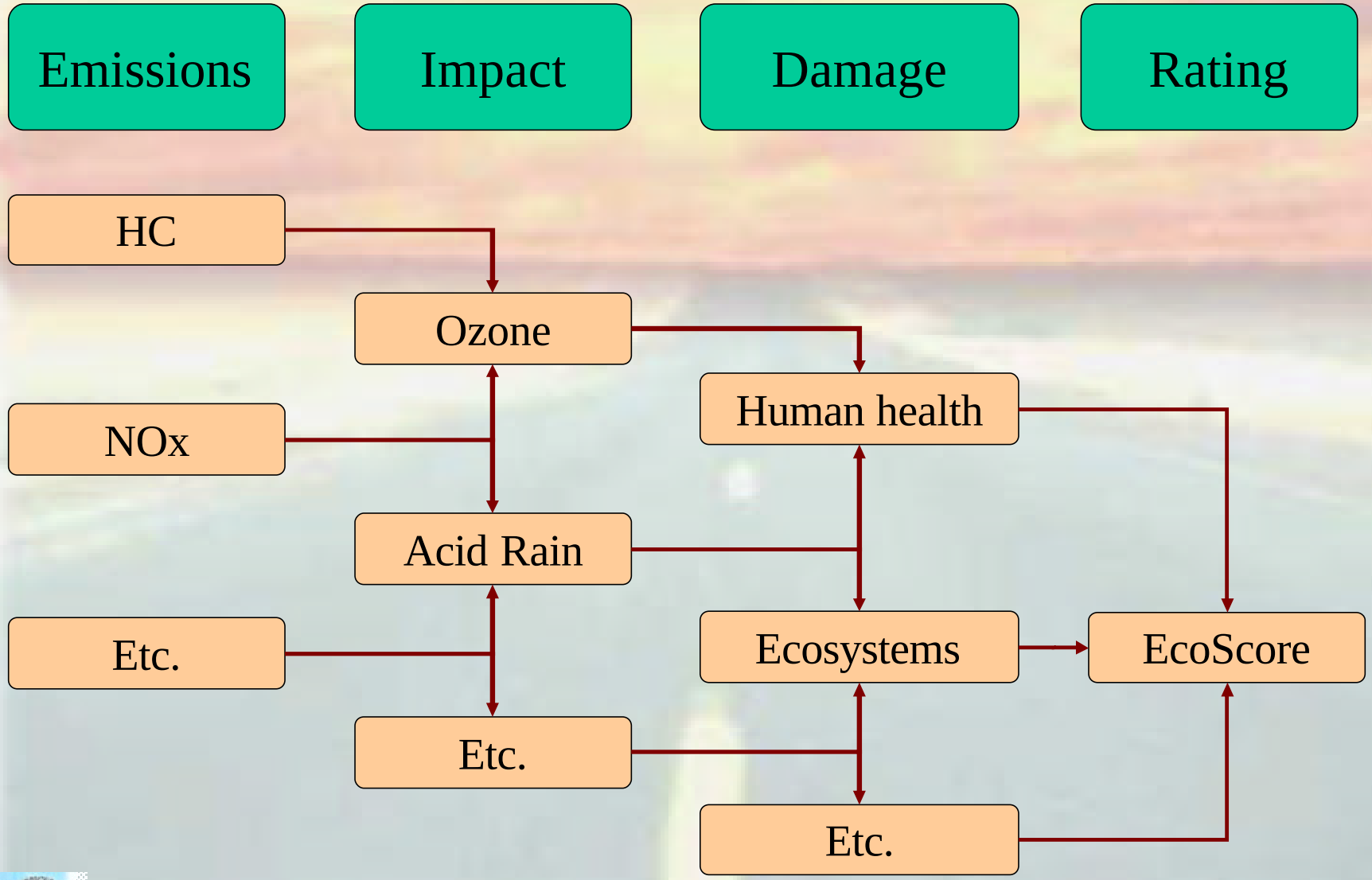
What is Clean, Environmentally friendly?

- Impacts
  - Greenhouse (CO_2, CH_4 et N_2O)
  - Ozone, photochemical air pollution (NOx, COV)
  - Acid Rain (NOx et SO_2)
  - Health (PM, SO_2, CO, NOx, COV et HAP)
  - Noise

- => Difficult to compare vehicles
  - Eg. Diesel : less greenhouse gasses, but more acid rain than petrol vehicle

- => Definition environmental rating

Ecoscore


Emissions
Impact
Damage
Rating
HC
Ozone
NOx
Human health
Acid Rain
Etc.
Ecosystems
EcoScore
Etc.
Etc.

International methodologies

- List of environmental vehicles (Auto-Umweltliste)
  - by “Verkehrsclub Deutschland”
  - in Germany, Switzerland and Austria
- Green Book
  - by ACEEE
  - in USA
- Ecolabelling
  - By VITO
  - in Flemish Region (Belgium)
- Eco-indicator ‘95 and ’99
  - By PRé Consultants
  - in the Netherlands
- Cleaner Drive
  - actual running EC project
  - http://www.cleaner-drive.com/

Overview - LCA

- Inventorying

  Well-to-Tank + Tank-to-Wheel

- Classification & Characterisation

  $Damage = x_1 \,.\, CO_2 + x_2 \,.\, CH_4 + \ldots$

- Normalisation

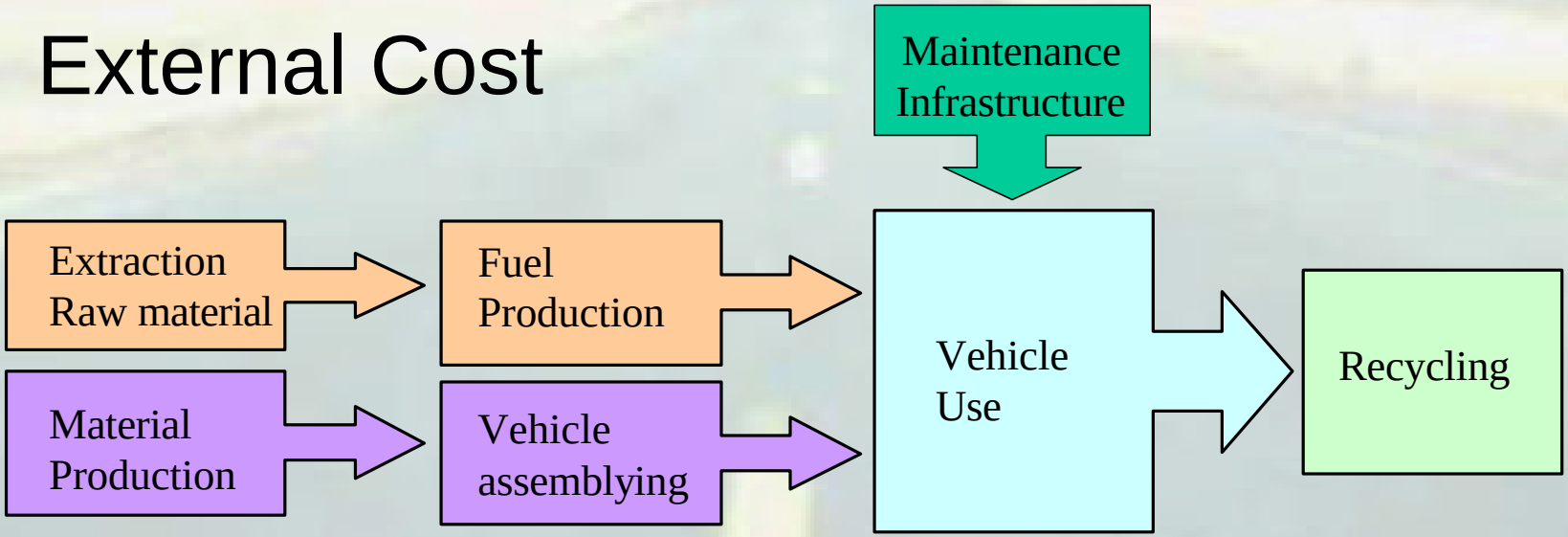
$$Damage(p.u.) = \frac{DamageVehicle\,(g/km)}{Damage\,ReferenceVehicle\,(g/km)}$$

- Weighting

  $EcoScore = x_1 \,.\, Damage1 + x_2 \,.\, Damage2 + \ldots.$

Emission sources

- Life Cycle Analysis (LCA)
- Cradle-to-grave
- Well-to-Wheel
- External Cost



Background Emissions of Fuels

	CO2 g/kWh	CO mg/kWh	Nox mg/kWh	NMHC mg/kWh	CH4 mg/kWh	SO2 mg/kWh	PM mg/kWh
gasoil	33.1	18.4	151.9	761.4	62.6	236.2	8.6
Diesel	24.5	16.6	129.6	315.4	56.5	174.2	3.6
LPG	21.6	14.8	116.3	202.7	58.0	114.1	5.4
Kerosene	23.0	16.2	130.7	298.4	57.6	192.6	4.3
heavy fuel oil	19.8	14.4	114.5	283.7	53.3	100.4	4.3
CNG	14.8	5.0	38.2	99.0	805.3	60.8	2.9
Biofuels-RME	108.7	493.2	871.9	280.4		245.5	66.6

Source: MEET - 1995

- **Extraction**
- **Offshore**
- **Transport of crude oil**
- **Refining**
- **Distribution** : transport and evaporation
- **Biofuel :** agriculture, transport, processing, distribution and storage, end use

Electricity Production

- Not produced at place of vehicle operation
- Cause background emissions; Function of
  - Type of power plant (nuclear, coal, gas, wind, water, …)
  - Relative contribution of each

- Very difficult to attribute a particular energy flow of an appliance to one particular power plant

- Average Electricity Production Mix
  - Treat all consumers of electrical energy equally
  - Gives a slightly “pessimist” image of electric vehicle
    = similar as taking together all types of thermal vehicle (old and new, diesel and petrol)

Average Electricity Production Mix

- Charged mostly during the night
  - Different composition of electricity production than average
  - Better efficiency and lower relative emissions
- Contains also old power plants
  - Introduction of electric vehicles in next ten years
  - Consider the investment policy of electricity production companies
  - Belgium: most new power plants are of Steam and Gas Combined Cycle (SGCC) type (efficiency of 53%)
- Combine central heating with electricity generator
  - Electricity (with an efficiency up to 50%)
  - Heat for the heating of buildings (overall efficiency higher than 80%)
- Zero emissions
  - From 2003 the electricity market in Europe is liberalised
  - Consumers can choose to buy e.g. emission free electricity
    - Dutch wind energy, Swiss hydro energy, French nuclear energy
  - EV charged with this electricity are ALWAYS emission free

Background Emissions Electricity Production

	CO_2	CO	NOx	NMHC	CH4	SO_2	PM
	g/kWh	mg/kWh	mg/kWh	mg/kWh	mg/kWh	mg/kWh	mg/kWh
MEET Belg. Mix-'95	339	60	1042	44	865	1921	98
Elektrabel 2001	290		440		1.73	420	36

- Emissions decreased significantly last 10 years
  - Do NOT use MEET
- MEET in the case of Belgium (1995)
  - 85% of CH_4 emissions
    - due to coal **extraction**
  - 93% of SO_2 emissions and 94% of PM emissions
    - due to **production** of electricity out of coal
  - Coal electricity plant 'only' produces 23.3% of electricity in Belgium

Total Emissions

- Impact on human health of emissions
  - Indirect emissions (e.g. PM) of
    - Crude oil refinery
    - Coal extraction, Etc.

    other impact than direct tailpipe emissions

  - High chimney ⇔ Tailpipe
    - Population Density
    - Emission Concentration
    - Emission Dispersion
    - Dosis-Effect

$$E_{totales} = E_{directes} + w_{ind}.E_{indirect}$$

- Impact on human health
- => Weighting (Green Book)
  - $w_{ind} = 0.5$ Fuel Refinery
  - $w_{ind} = 0.1$ Electricity Production
- Other Impacts
  - $w_{ind} = 1.0$

Characterisation of damage

	Unit	Source	CO2	HC	NOx	CO	CH4	N2O	SO2	PM
al Warming	DALY/kg	Ecolabel 99	**2,10E-07**				**4,40E-06**	**6,90E-05**		
	GWP	IPCC	**1,00E+00**				**2,30E+01**	**2,96E+02**		
piration - Organic Components	DALY/kg	Ecolabel 99		**6,46E-07**			**1,28E-08**			
piration - Non-Organic Components	DALY/kg	Ecolabel 99			**8,87E-05**	**7,31E-07**			**5,46E-05**	
cer	DALY/kg	Ecolabel 99								**9,78E**
an Health	Damage Cost (€/kg)	Green Book		**3,70E-01**	**4,94E+00**	**3,00E-02**			**2,34E+01**	**3,97E**
quality	€/Ton	Cleaner Drive		**1,20E+00**	**3,00E+00**	**1,03E+00**			**6,76E+00**	
systems – Ecotoical Emissions	PDF,M2,year/kg	Ecolabel 99								
systems – acidification & ophisation	PDF,M2,year/kg	Ecolabel 99			**5,71E+00**				**1,04E+00**	
tochemical Air Pollution	ppb/O3/Mt/an			**3,10E-01**	**3,70E-01**					
Rain	%	VITO			**9,00E+01**				**1,00E+01**	
dings	[Euro/kg]	ULB-CEESE							**8,26E+00**	

PM10 & PM2,5
TSP
NO & NO2

- 1,3 Butadiene
- Benzene
- NMHC
- Formaldehyde

- Methane
- Toluene
- Xylene
- HAP

- Benzo(a)pyrene (BaP)
- Benzo(a)anthracène
- Dibenzo(a)anthracène
- Lead

Normalisation

$$Damage\,(p.u.) = \frac{Damage\,Vehicle\,(g/km)}{Damage\,ReferenceVehicle\,(g/km)}$$

- Distance to Target
  - Goals for Better Environment
  - Technologically Possible

  - How Far Are Vehicle Emissions Lower Than Regulations
    - Regulated Emissions (EURO IV-Petrol)
      - » CO = 1.00 g/km
      - » NOx = 0.08 g/km
      - » HC = 0.10 g/km
      - » PM = 0.00 g/km
    - FC depending Emissions (CO_2)
      - » CO_2 = 120 g/km
      - » SO_2 = 0.0038 g/km
      - » Indirect Emissions
    - Noise
      - » 70 dB(A)

Damage Weighting

$$EcoScore = \sum_j X_j . q$$

Damage		IFEU	Green Book	Aminal	Ecolabel 99	BIM
lth		10%	50%	20%	40%	
	Cancer	15%				20%
	Respiration - Organic Components					15%
	Respiration - Non-Organic Components					15%
bal Warming		40%	50%	40%		25%
ironment		10%			40%	10%
	Acid Rain			10%		
	Photochemical			20%		
	Ecosystems – Ecotoical Emissions					
	Ecosystems – acidification & eutrophisation					
sources					20%	
ed		5%				
se		20%		10%		10%
dings						5%
t Pollution						
gestion						
ety						

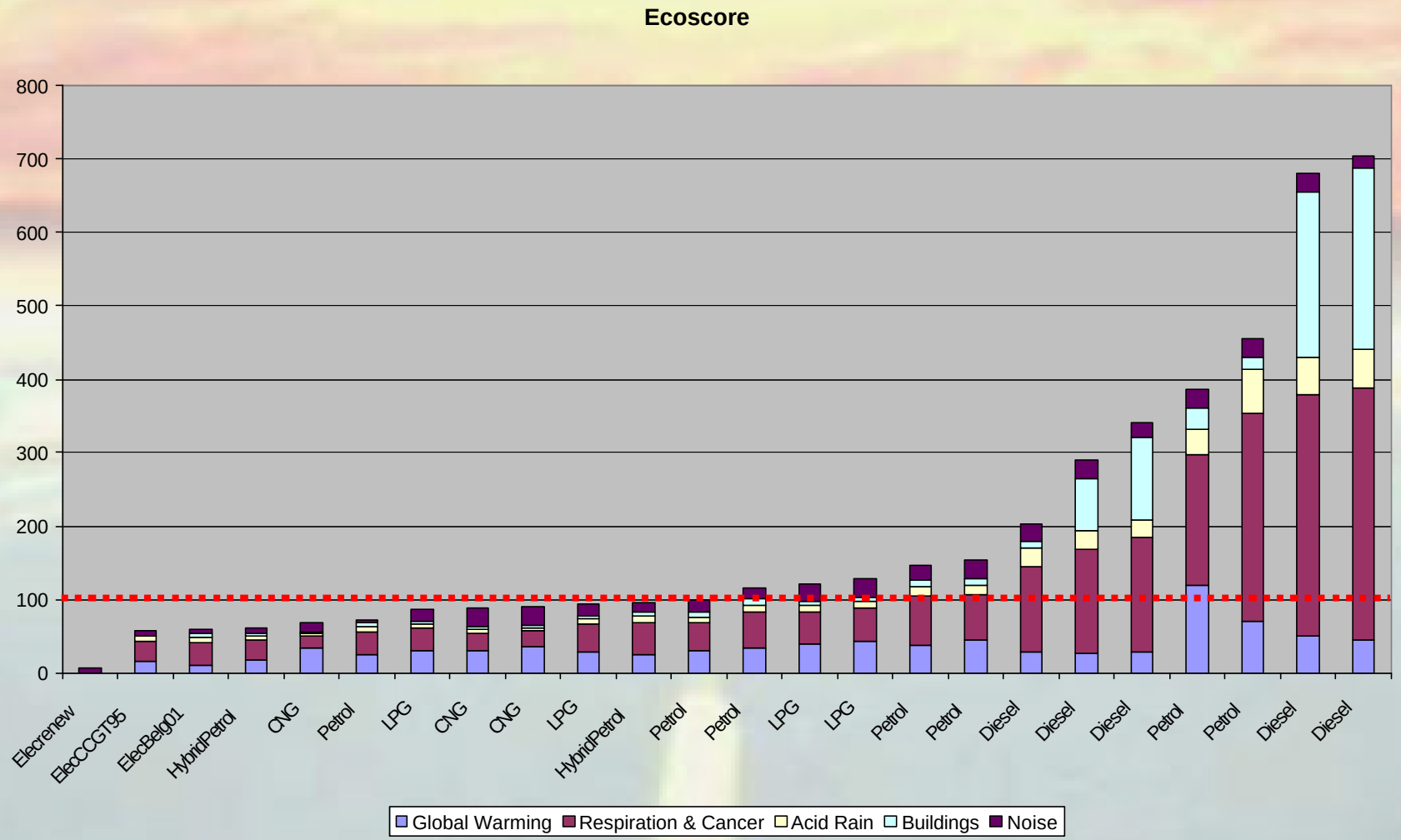
$$\text{Ecoscore} = 25\% \cdot Q_{greenhouse} + 50\% \cdot Q_{respiration\ \&\ cancer} + 10 \cdot Q_{acidificaton} + 5\% \cdot Q_{buildings} + 10\% \cdot Q_{noise}$$

How Could ?

- Availability and Accuracy of data
  - Simplification of EcoScore Model
  - Only
    - Type approval : CO, HC, NOx, PM, Noise
    - Fuel depending : CO_2, SO_2, CH_4, N_2O

Some examples - Ecoscore

(Belgian – Brussels situation)



Remarks

- ICE
  - Optimistic EcoScore
  - Based on Type approval test
  - Tailpipe emissions
    - Real life emissions higher
    - some high polluters possible
    - close to population
  - Get worse in time (age/maintenance)
- EV
  - Pessimistic EcoScore
  - Based on real Electricity emissions
  - Chimney Emissions
    - Real Measured Emissions
    - Controlled
    - Dispersion, concentration o emissions and density of population
  - Get better in time (investment policy)

Conclusions

- In function of available data (and considered examples):
  - ***Electric*** vehicles are the cleanest
    with differences in function of the electricity production mode
  - Also the evaluated ***hybrids*** can be considered as Clean Vehicle
  - ***LPG*** en ***CNG*** can be considered as clean
    with a larger benefit for the CNG vehicles compared to LPG
    (LPG installation and CNG engine have an important impact on the real life emissions
  - Some small ***petrol*** vehicles can be considered as clean
  - Traditional ***diesel*** vehicles can not be considered as Clean Vehicles
    due high NOx and PM emissions and their impact on human health