Introduction
Energy Economics in Transport

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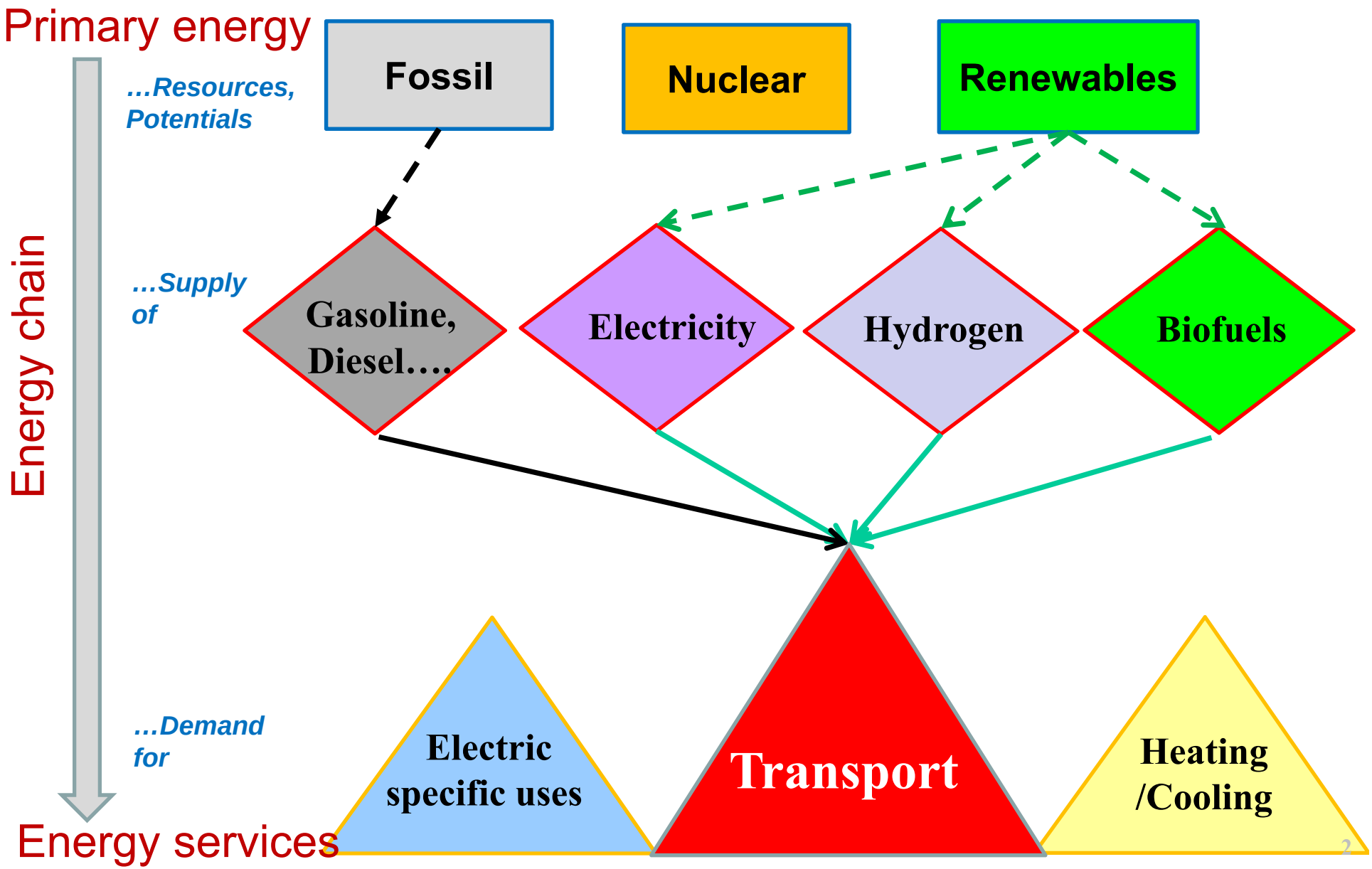
Energy system



Content

1. Introduction
2. Key world and EU energy statistics
3. Historical developments
4. Major indicators of the transport sector
5. Alternative fuels and alternative automotive powertrains

Introduction

Basic principle:

$$S=f(E, \eta(Tc), \eta(Tis))$$

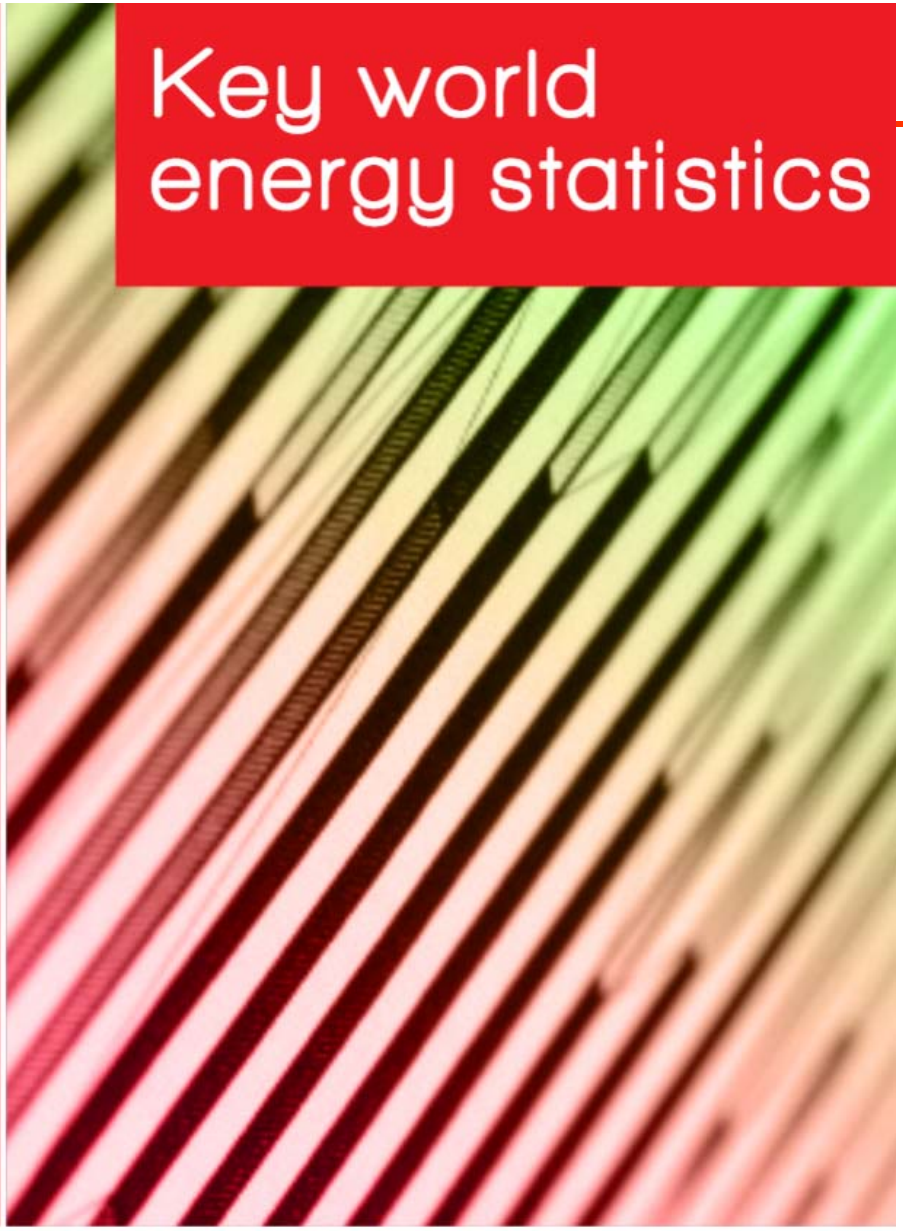
Service:
km driven

Fuel mix,
Fuel demand

Efficiency:
Liter/100 km

Infrastructur

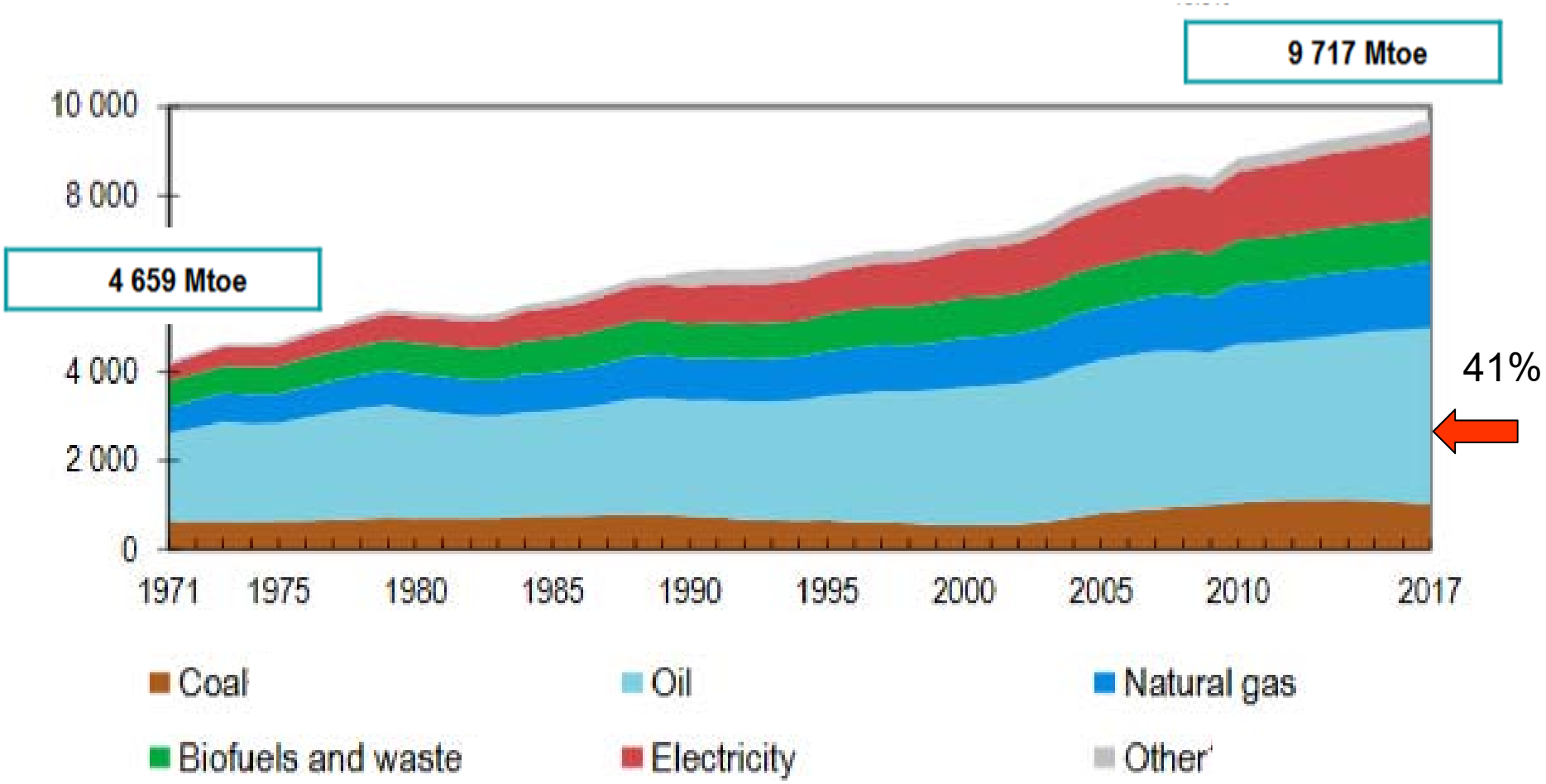
Key world energy statistics



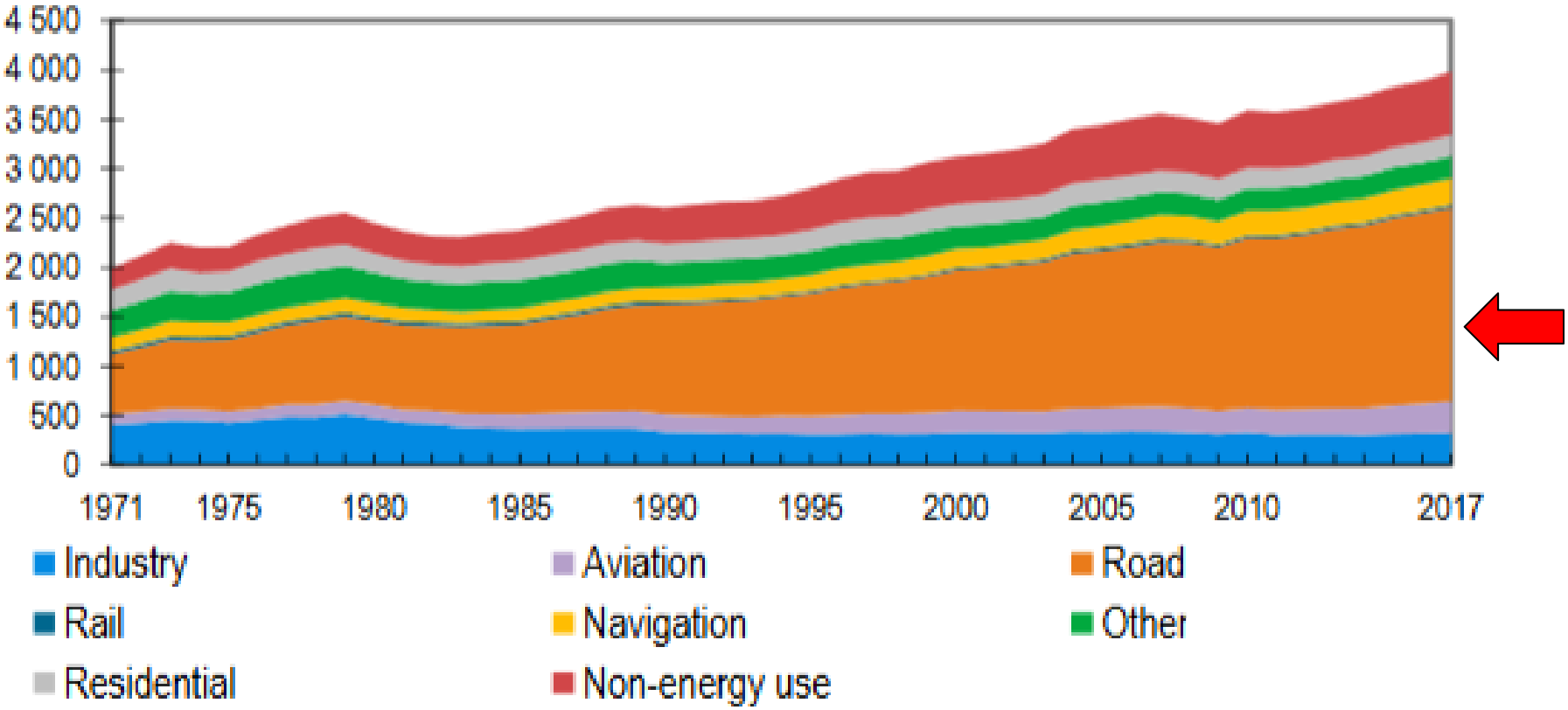
IEA

2019

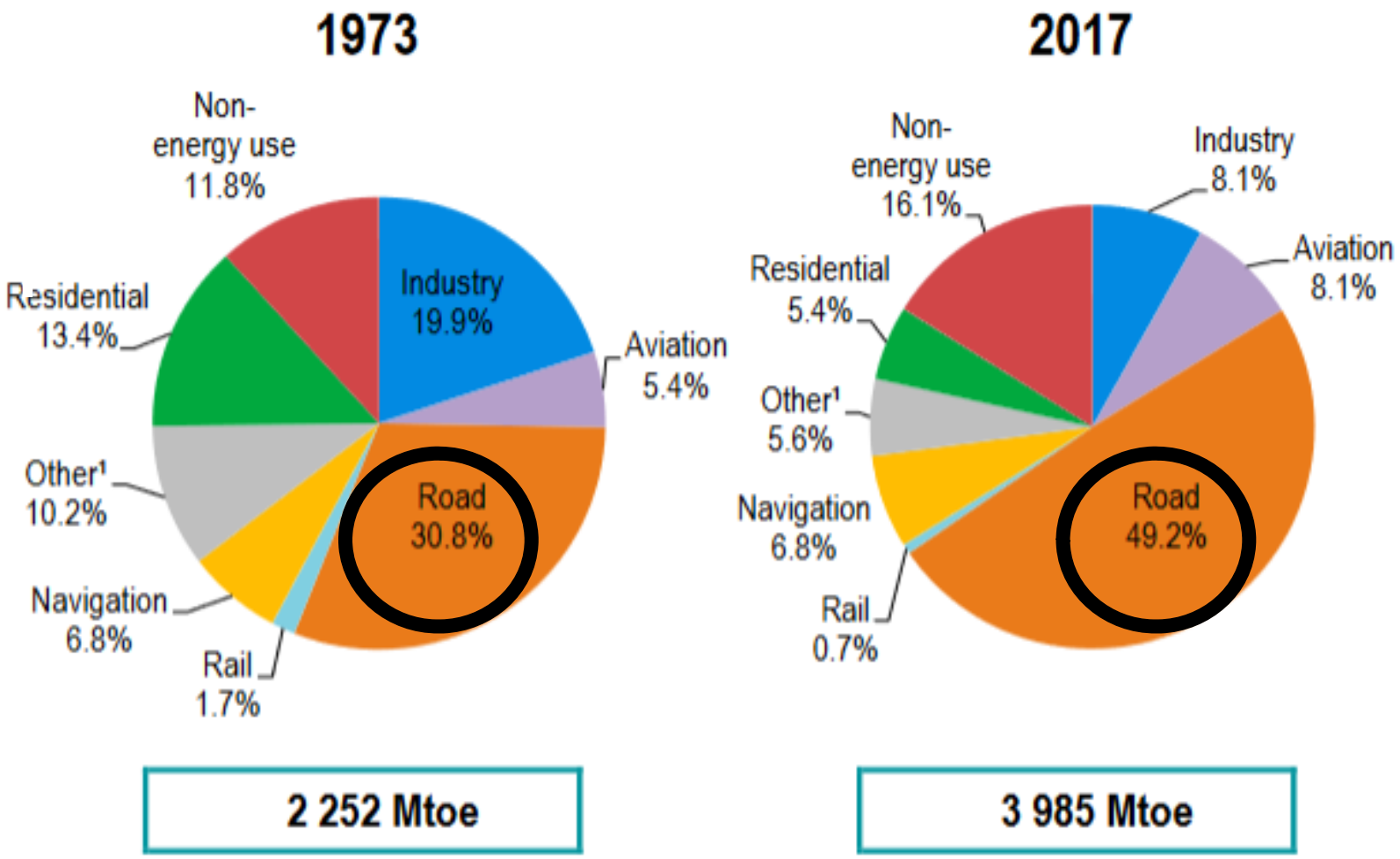
World total final consumption by fuel (Mtoe)



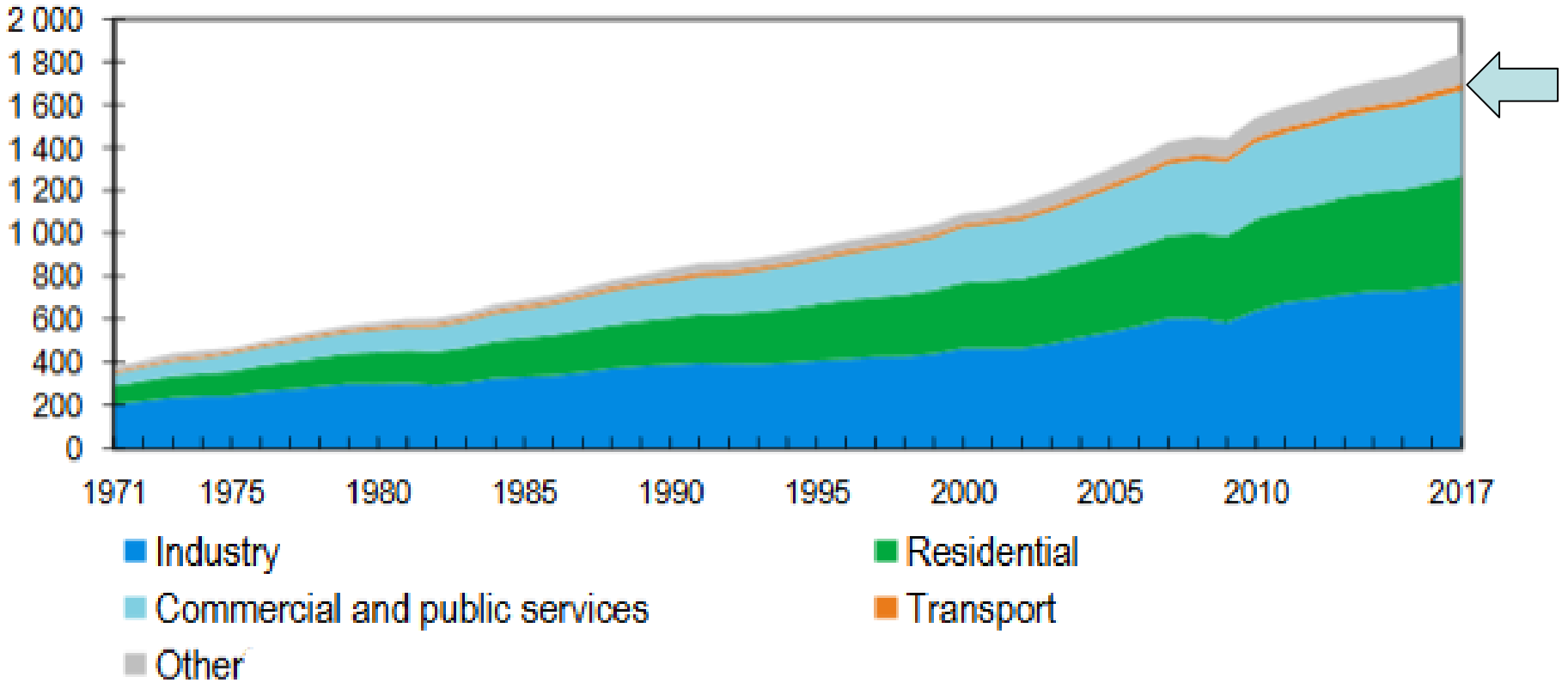
Total final consumption by sector: oil (Mtoe)



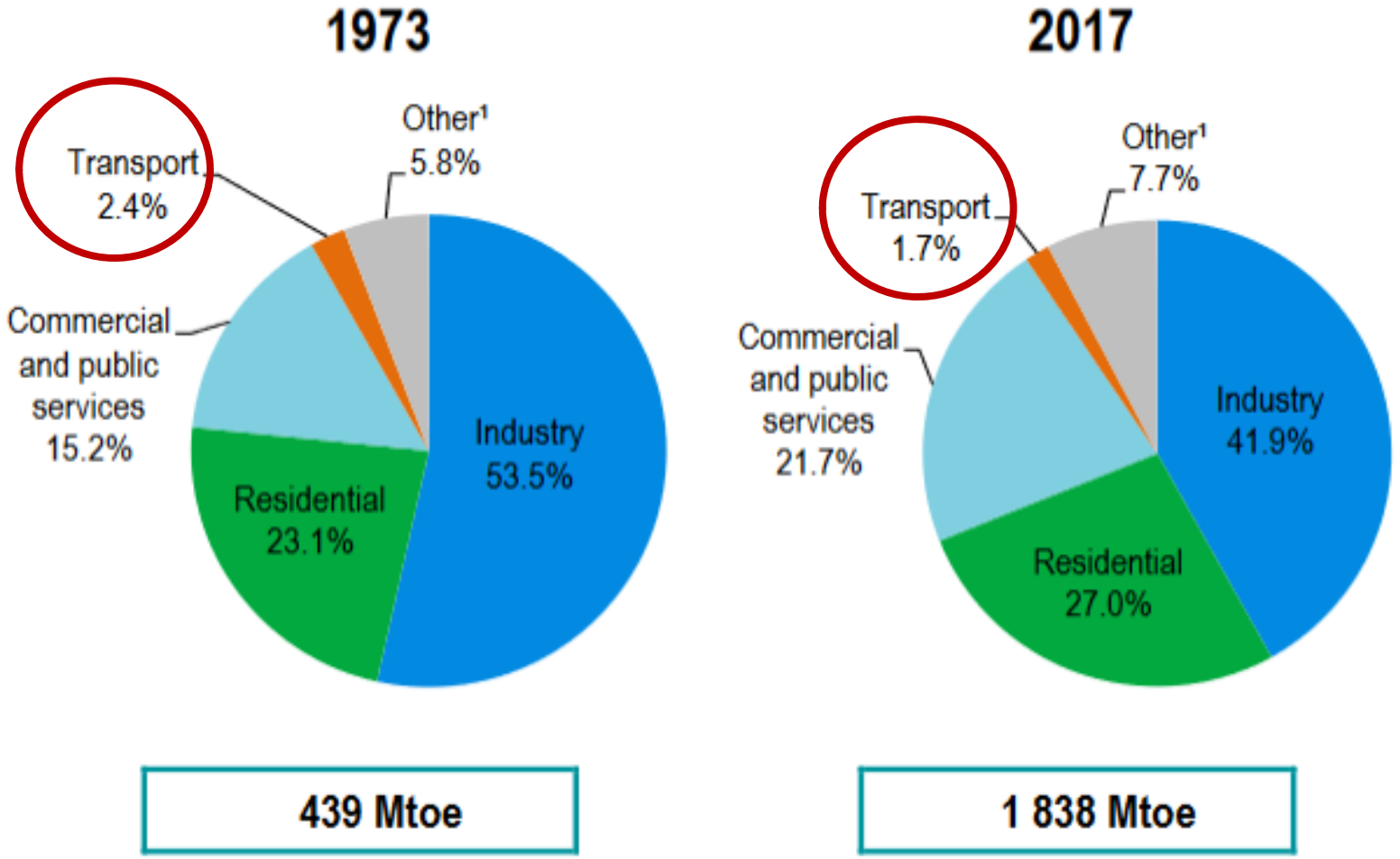
1973 and 2017 shares of world oil consumption



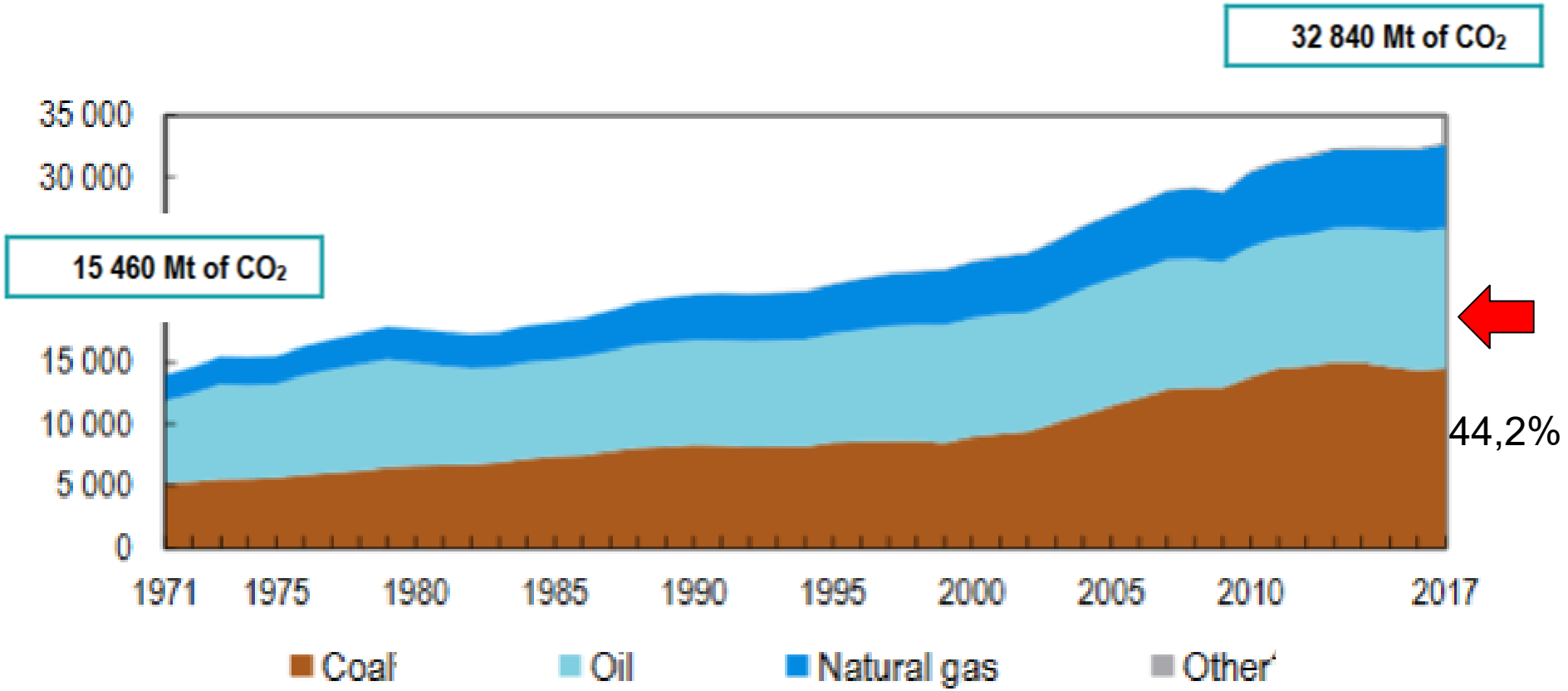
Total final consumption by sector: electricity (Mtoe)



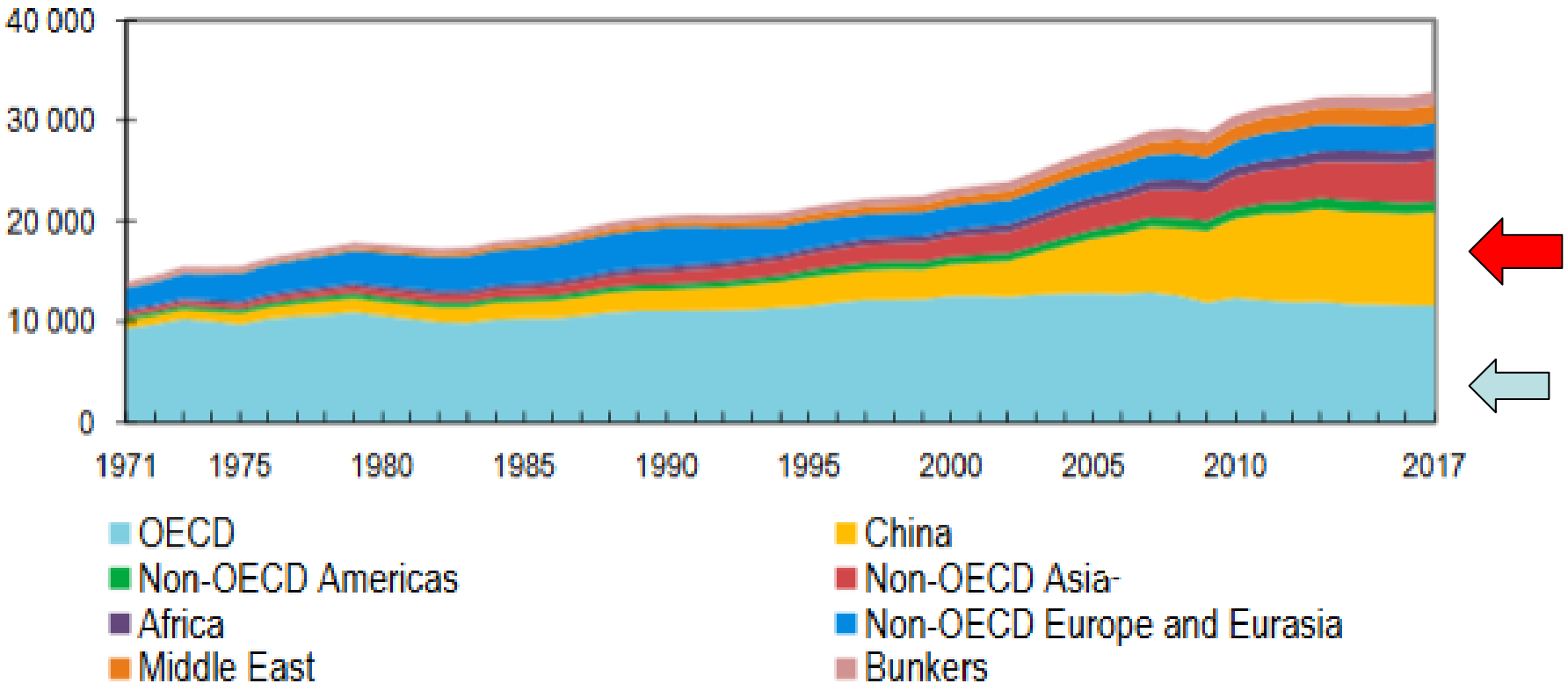
Shares of world electricity consumption



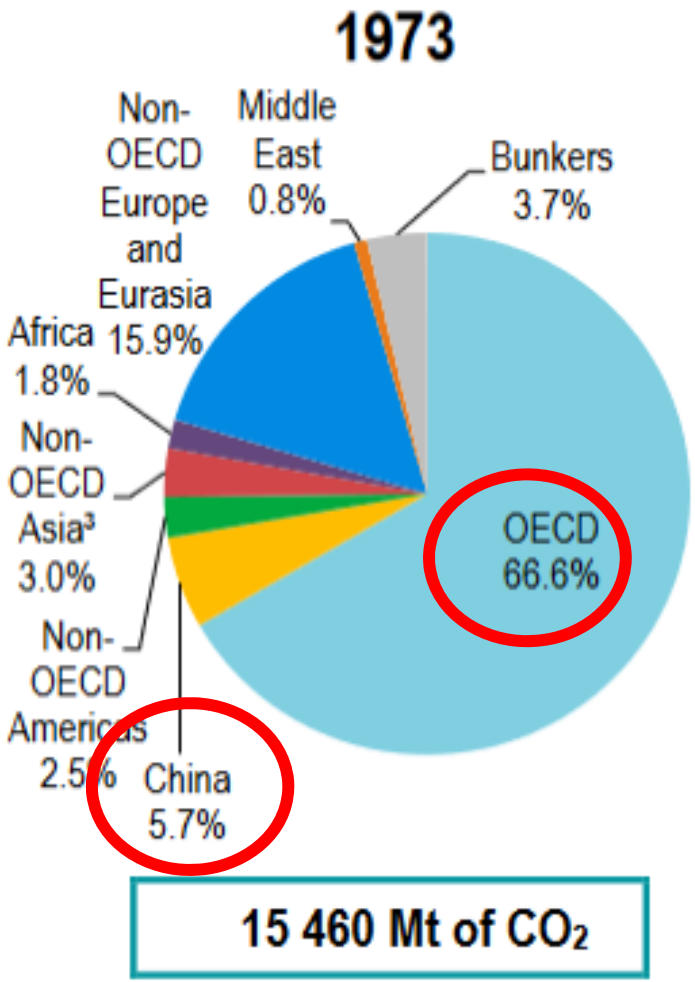
World CO2 emissions from fuel combustion from 1971 to 2017 by fuel (Mt of CO2)

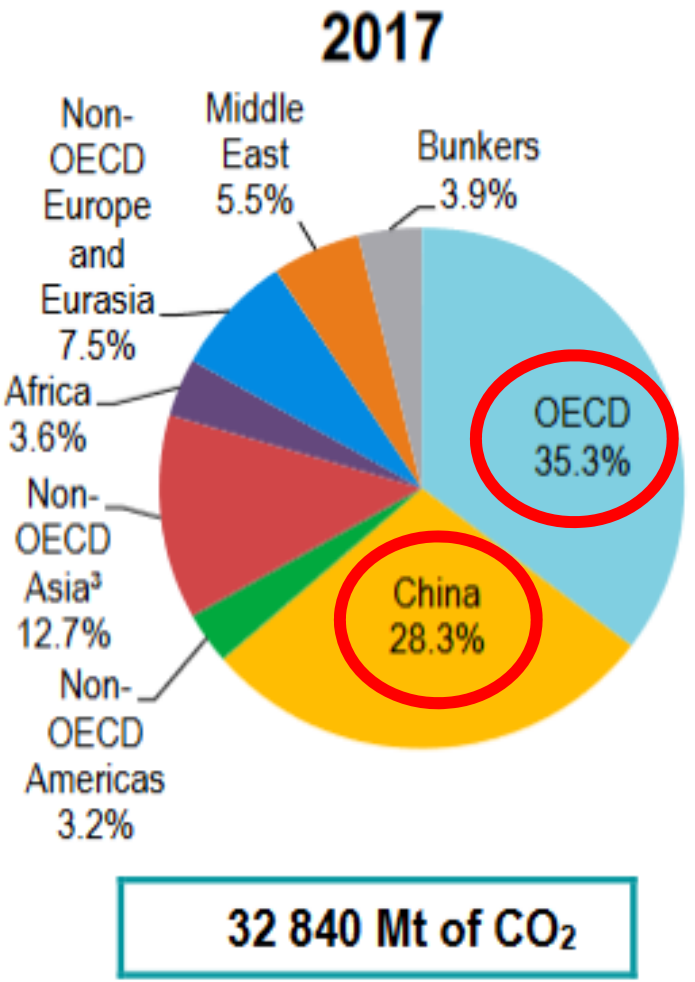


World CO2 emissions from fuel combustion by region (Mt of CO2)



1973 and 2017 regional shares of CO2 emissions from fuel combustion

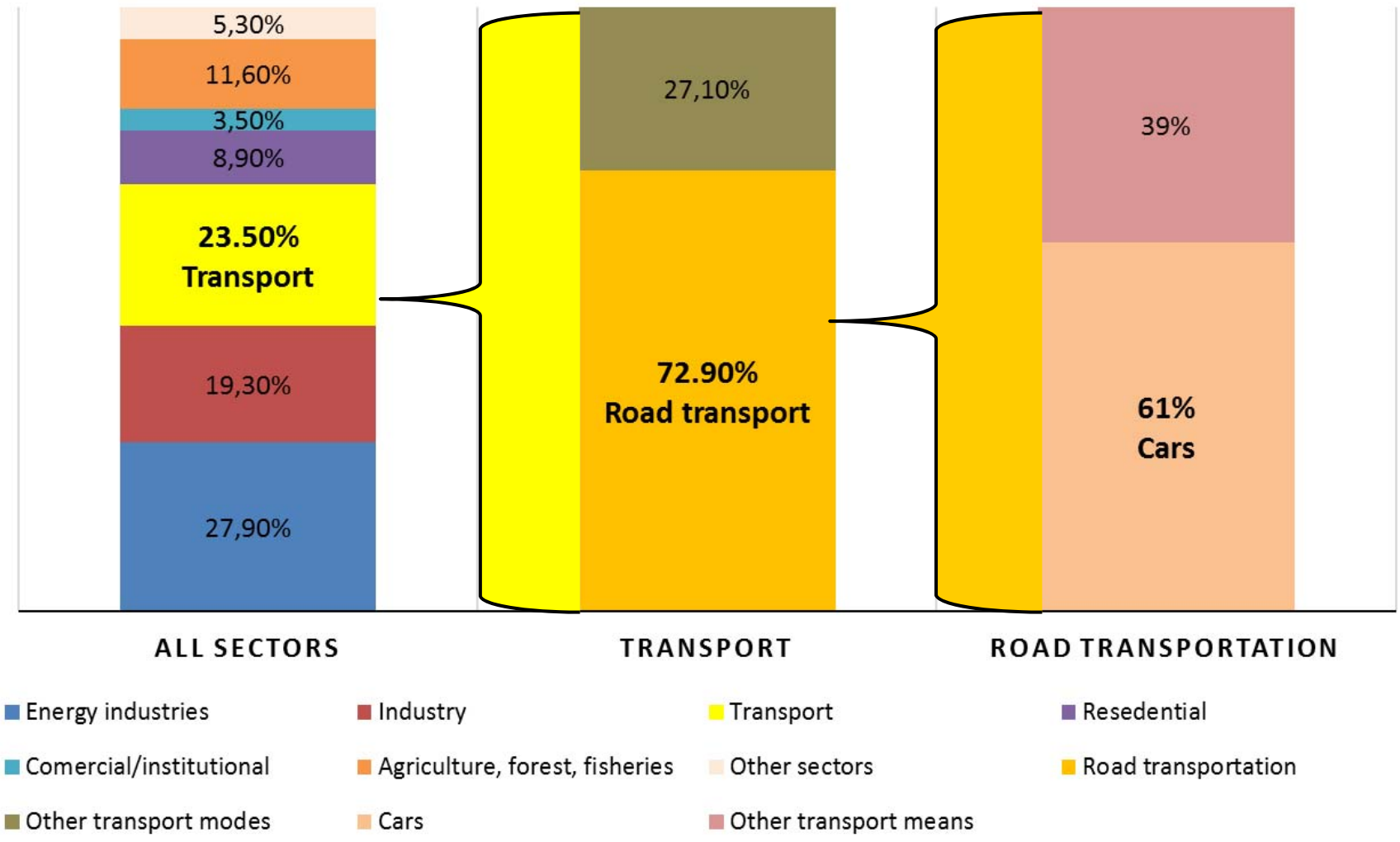




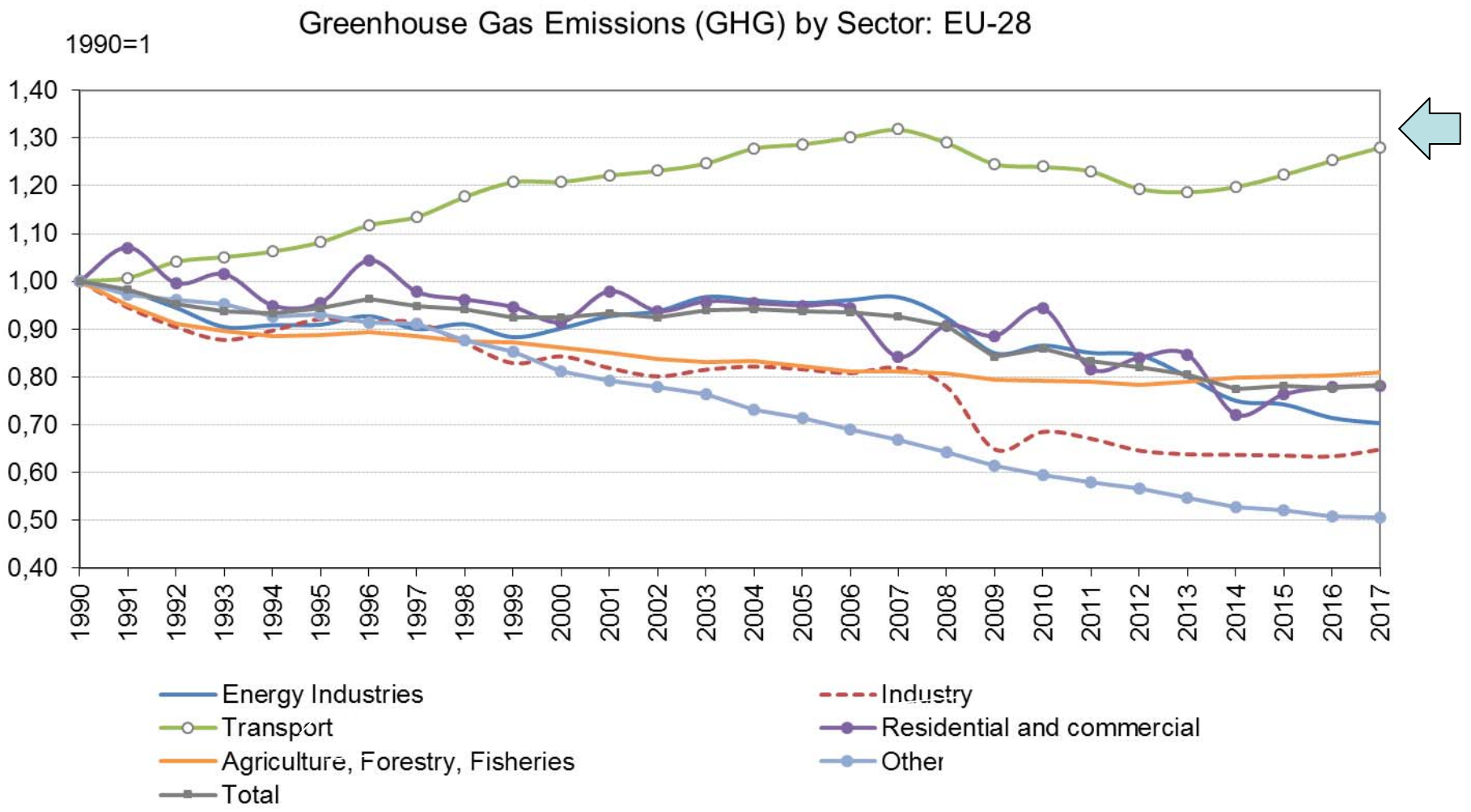
Key EU statistics

Statistical pocketbook 2019

GHG emissions in EU 28

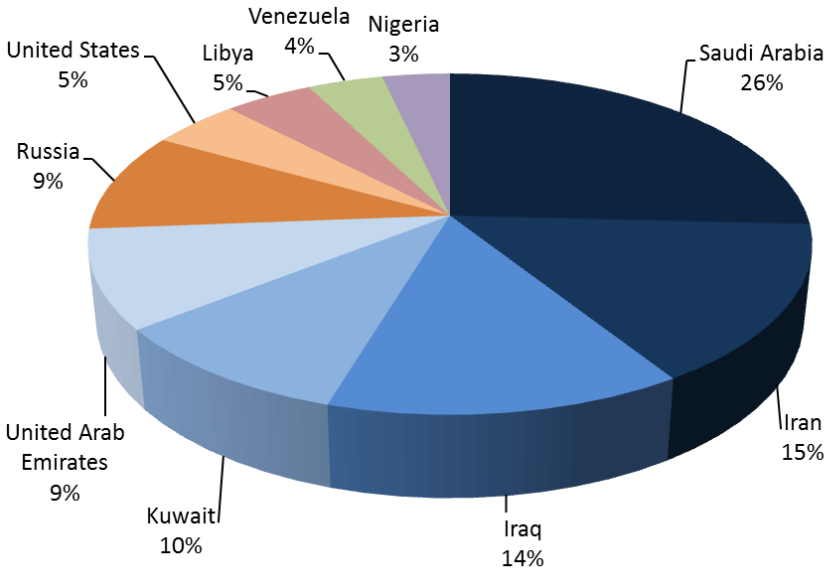


GHG


Greenhouse Gas Emissions (GHG) by Sector: EU-28
1990=1
1,40
1,30
1,20
1,10
1,00
0,90
0,80
0,70
0,60
0,50
0,40
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Energy Industries
Industry
Transport
Residential and commercial
Agriculture, Forestry, Fisheries
Other
Total

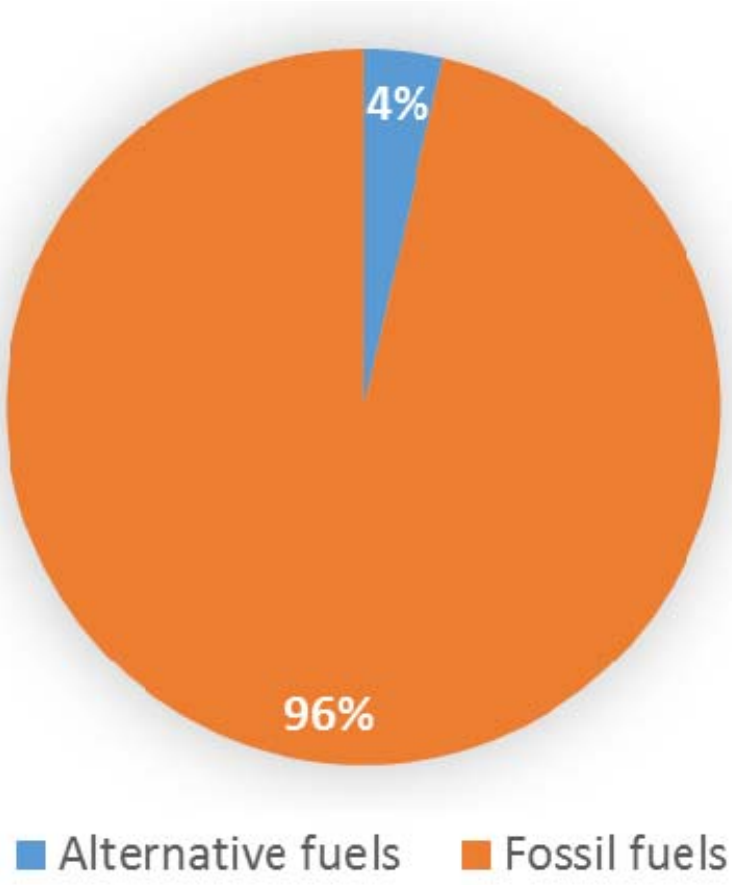
Transport sector

- Fossil fuels
- Least-diversified sector

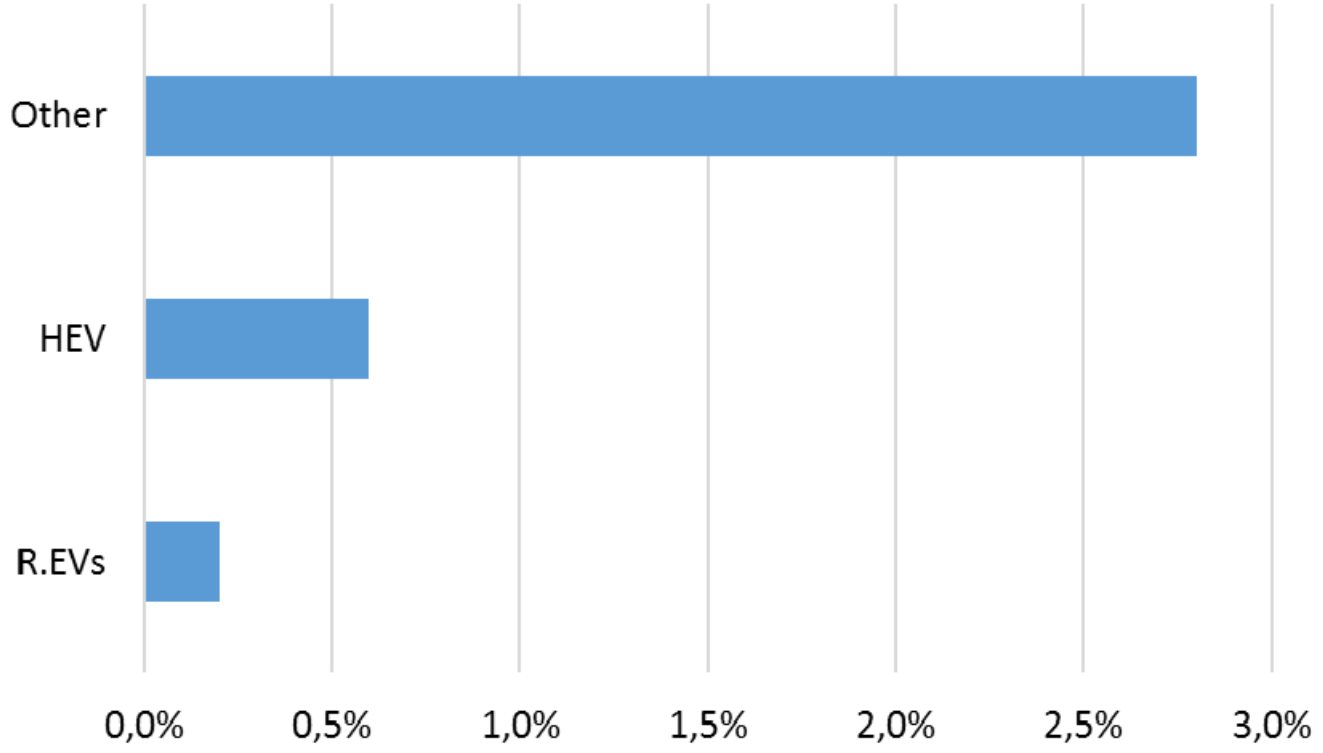


Countries with largest conventional oil reserves

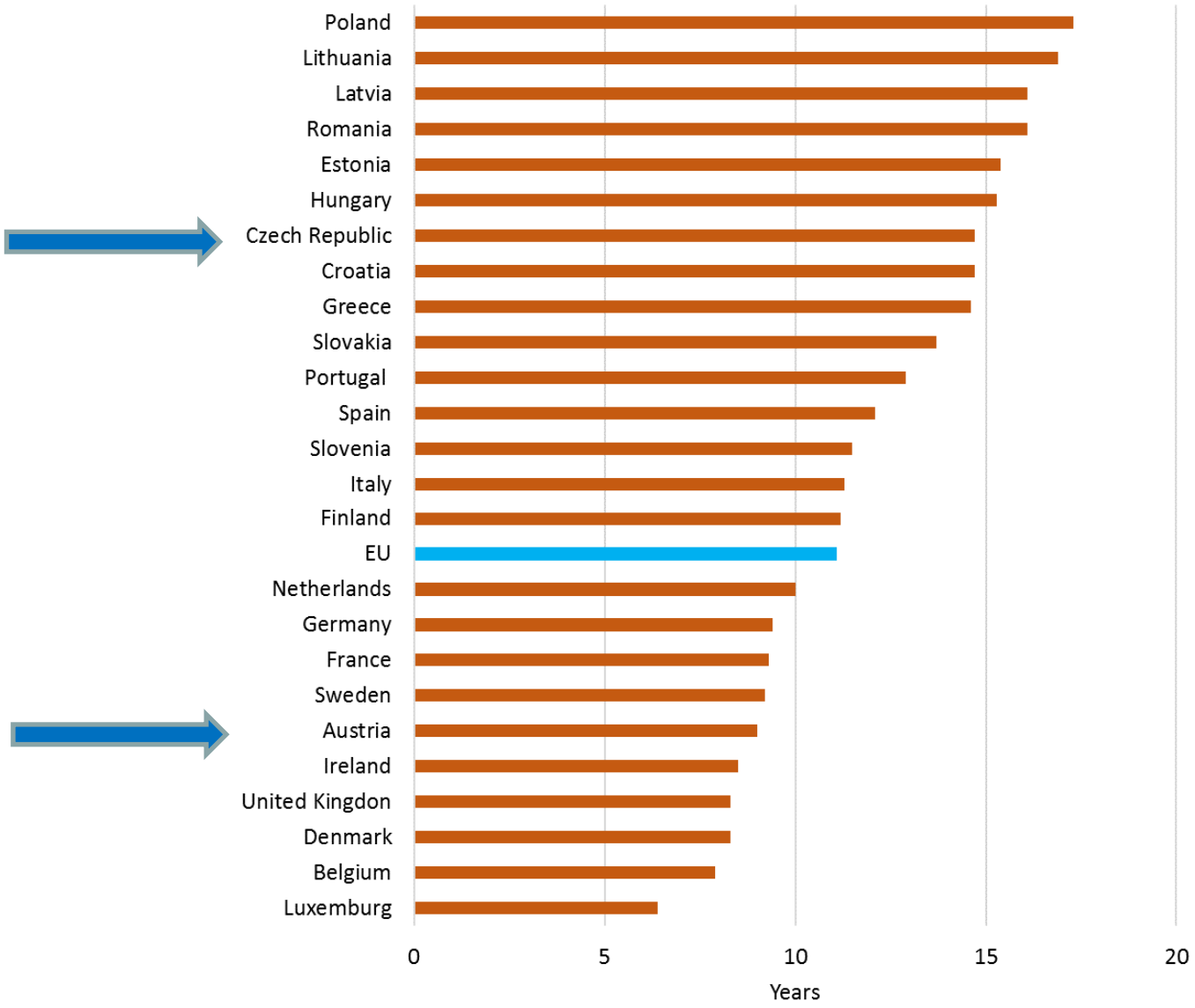
Share of alternatively-powered vehicles in the EU, 2017



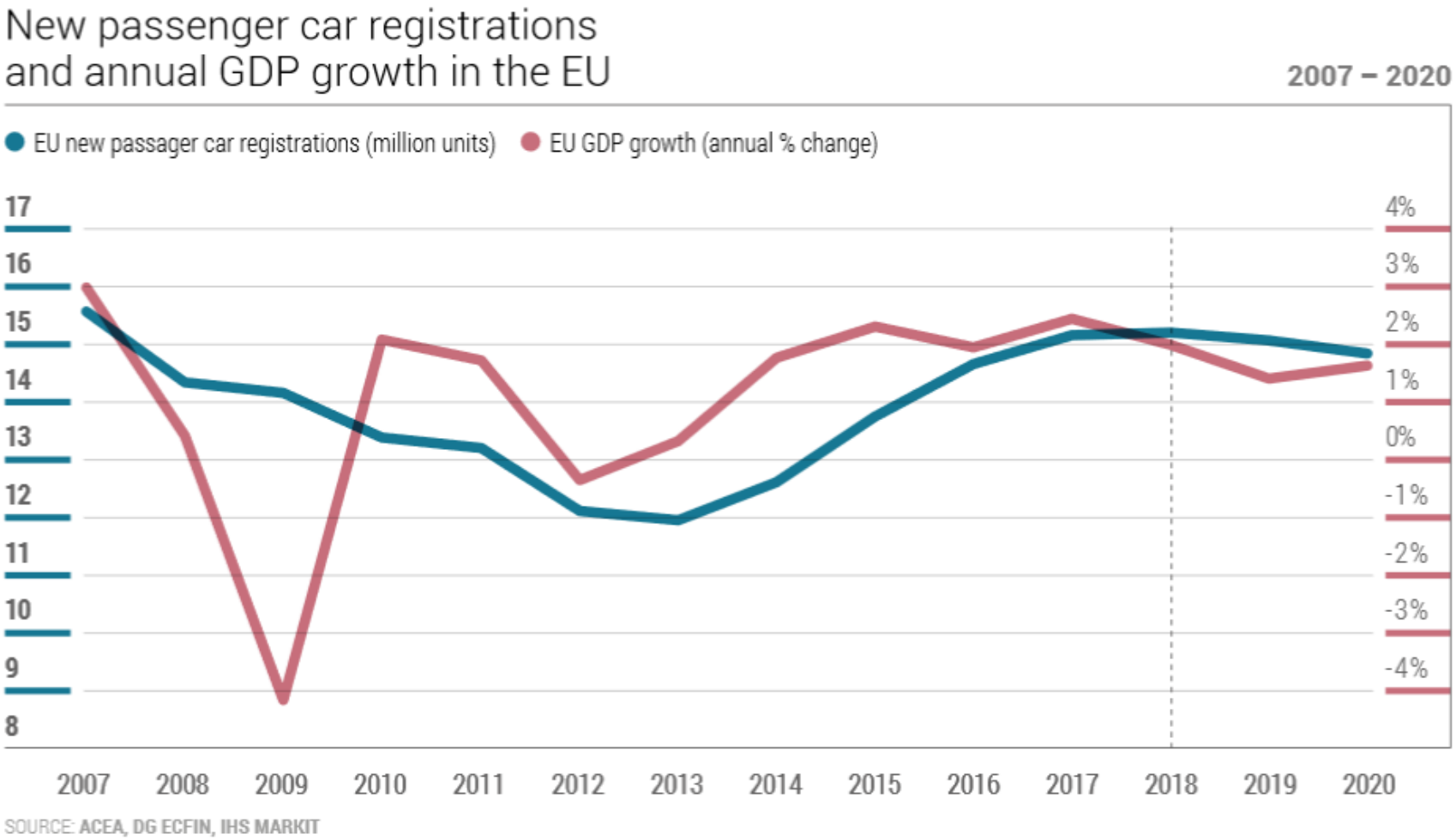
Share of alternatively-powered vehicles in the EU, 2017



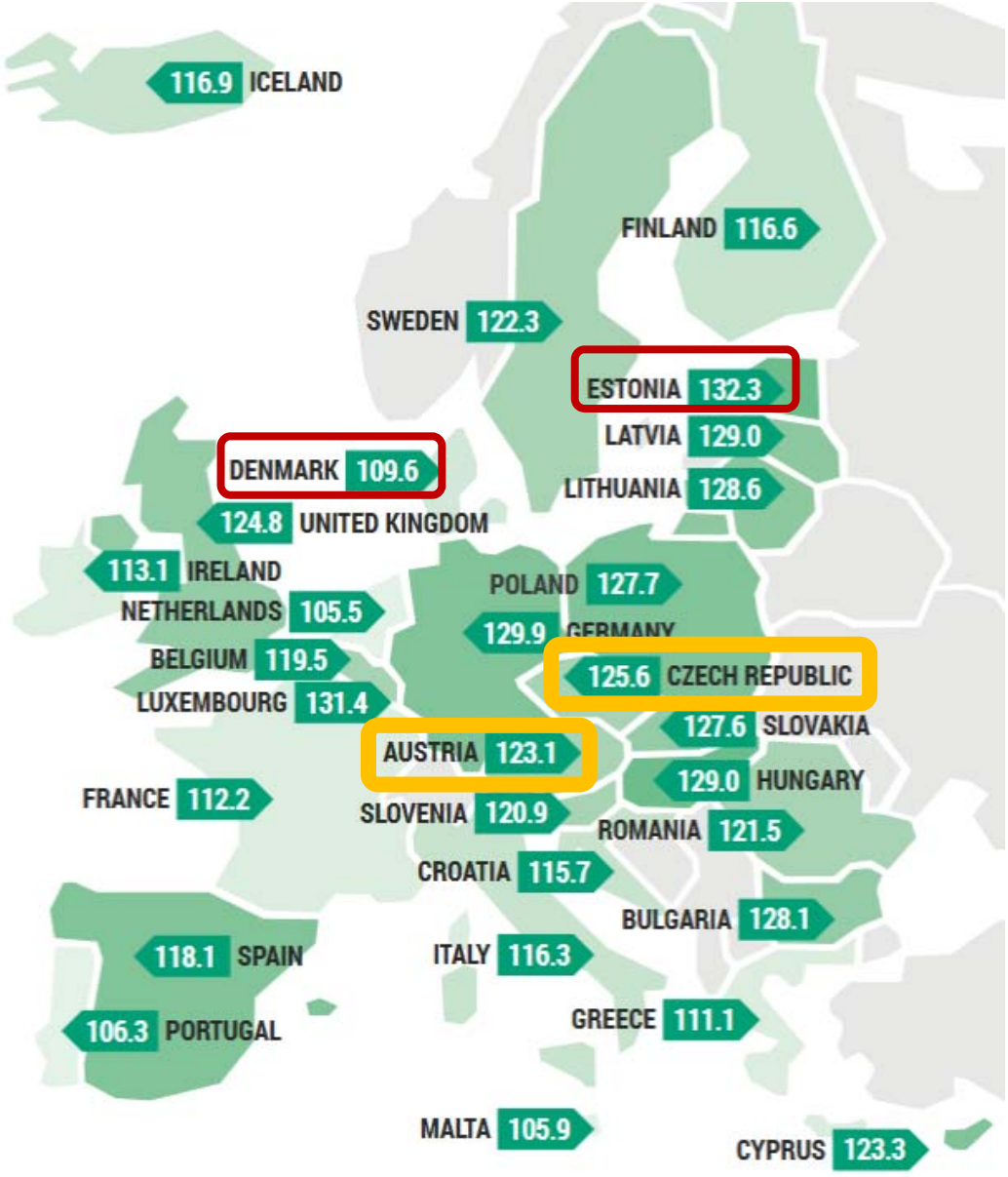
Average age of the EU vehicles, 2017

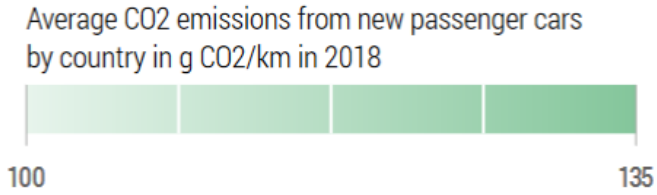


New passenger car registrations vs GDP



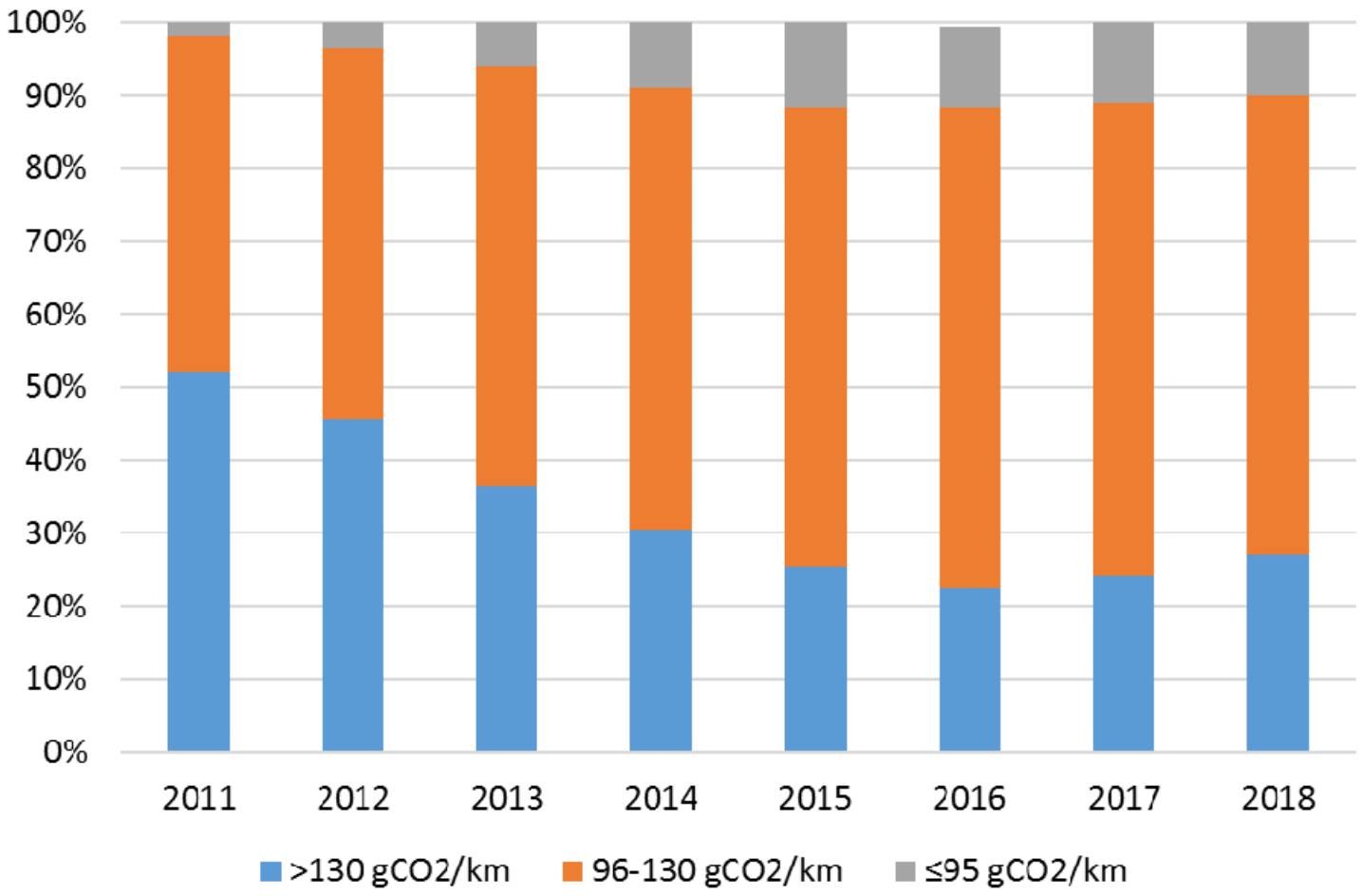
Average CO2 emissions from new passenger cars by country





The EU average: 120.6g CO2/km

New passenger cars in the EU by emissions classes



Historical developments

Amount of transport services per capita

Horse power

Sailing ship

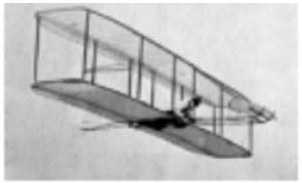
Steam machine, steam railway

Electricity, combustion engine

based on commercial energy

based on non-commercial renewable energy

time

1850	1900	1950	2000	2050
				
				?
				

Resistance to New Technology

Against Railways

in 1838

MOTHERS LOOK OUT FOR YOUR CHILDREN!

ARTISANS, MECHANICS, CITIZENS!

When you leave your family in health must you be hurried home to mourn a

DREADFUL CASUALITY!

PHILADELPHIANS your RIGHTS are being invaded' regardless of your interests or the LIVES OF YOUR LITTLE ONES THE CAMDEN AND AMBOY with the assistance of other companies, without a Charter and in VIOLATION OF LAW, as decreed by your Courts, are laying a

LOCOMOTIVE RAIL ROAD!

Through your most Beautiful Streets to the RUIN of your TRADE, annihilation of your RIGHTS and regardless of your PROSPERITY and COMFORT. Will you permit this' or do you consent to be a

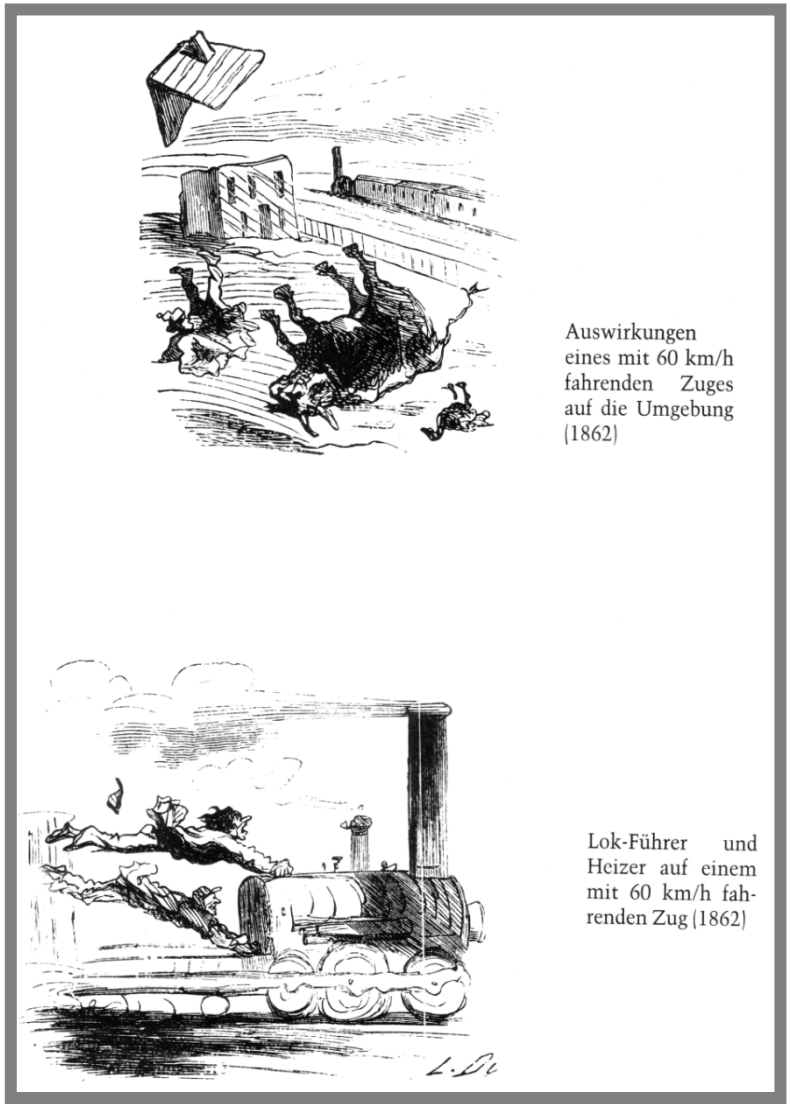
SUBURB OF NEW YORK!!

Rails are now being laid on BROAD STREET to CONNECT the TRENTON RAIL ROAD with the WILMINGTON and BALTIMORE ROAD, under the pretence of constructing a City Passenger Railway from the Navy Yard to Fairmount!!! This is done under the auspices of the CAMDEN AND AMBOY MONOPOLY!

RALLY PEOPLE in the Majesty of your Strength and forbid THIS

OUTRAGE!

Skepticism and Resistance



Auswirkungen eines mit 60 km/h fahrenden Zuges auf die Umgebung (1862)

Lok-Führer und Heizer auf einem mit 60 km/h fahrenden Zug (1862)

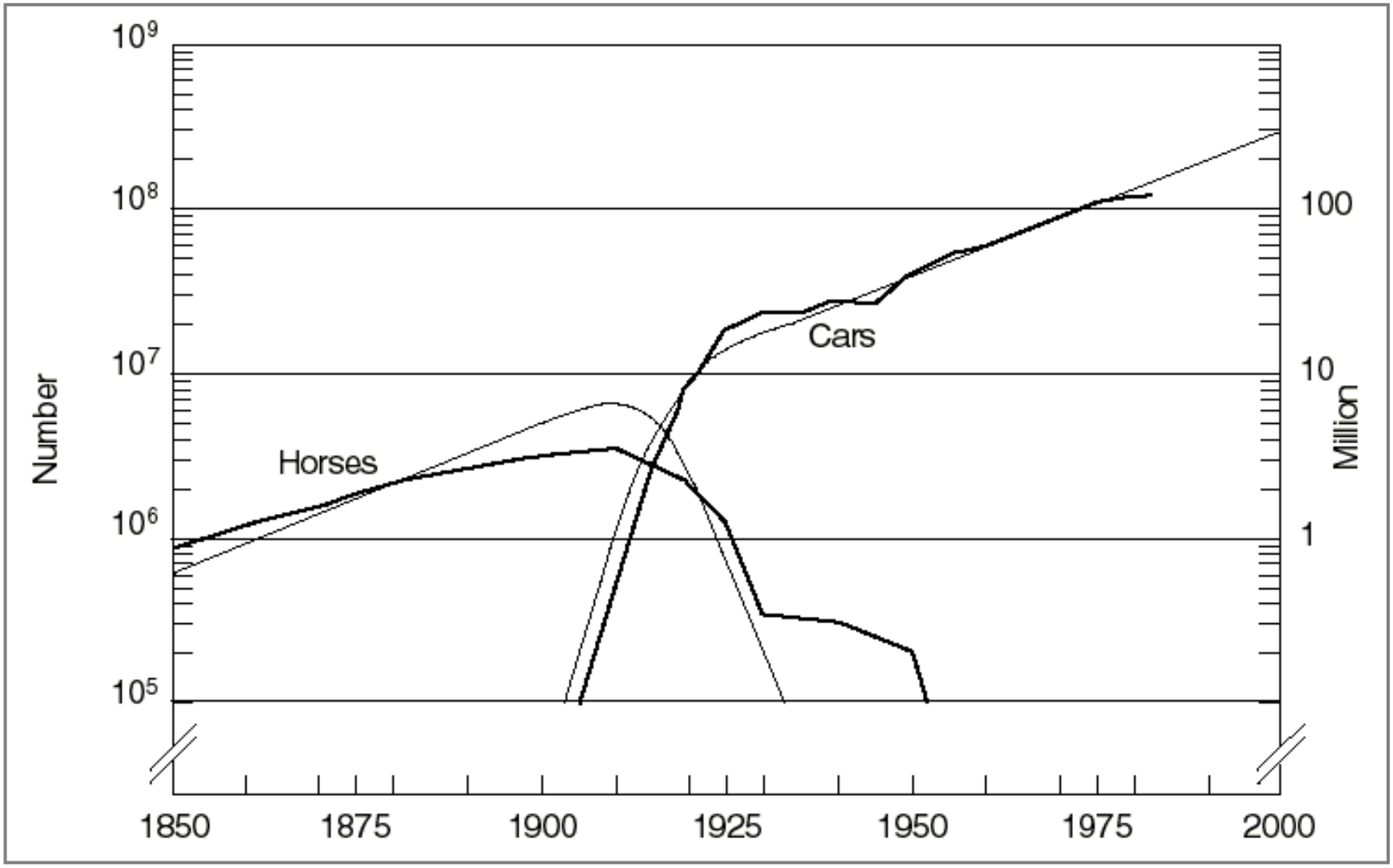
Innovation:

Skepticism and Resistance in View of the Unknown

Speed kills..... 19th century skeptical German cartoons reflecting Science‘s (Prussian Academy of Sciences) verdict

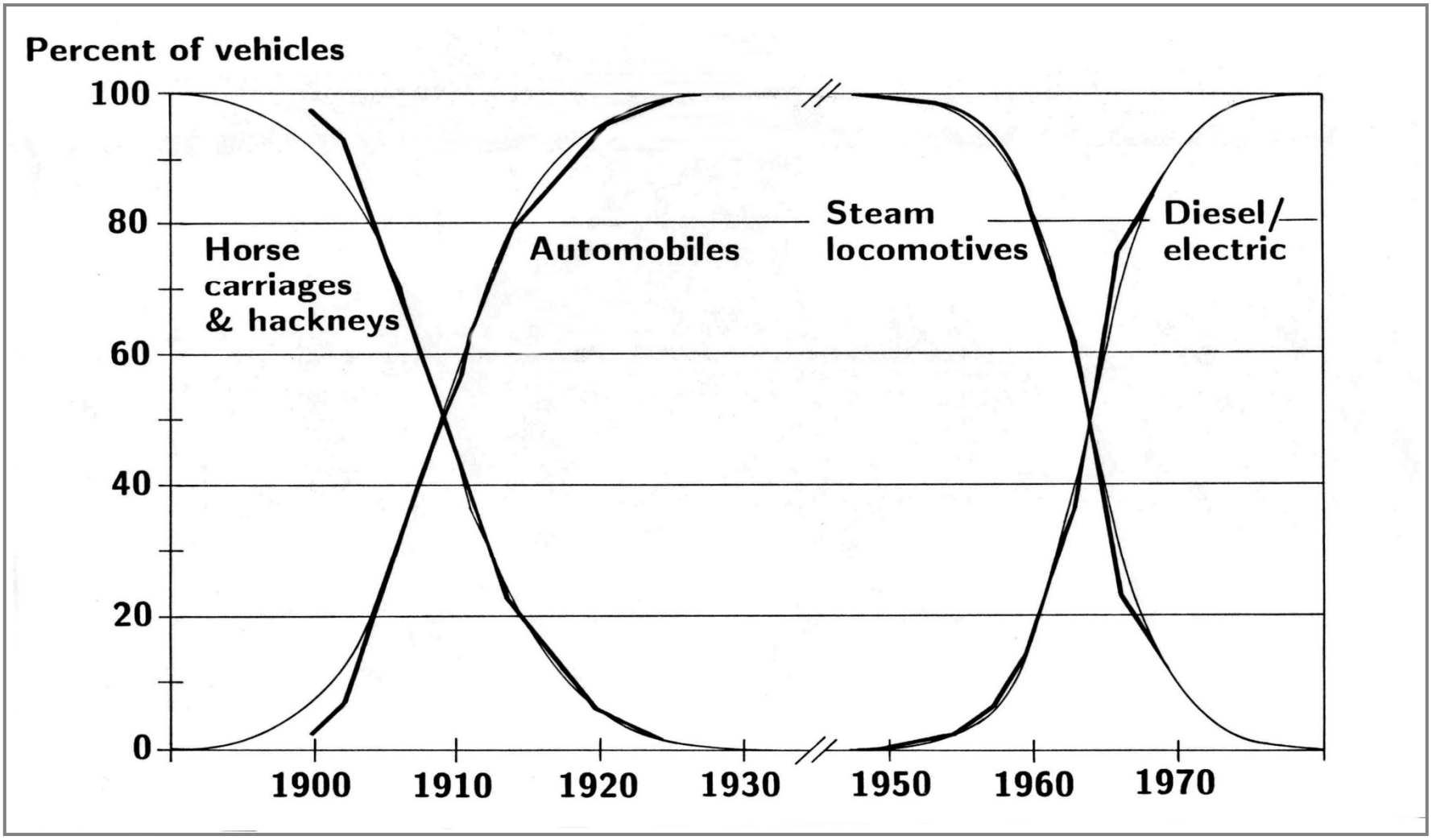
1842

USA – Number of Horses and Cars



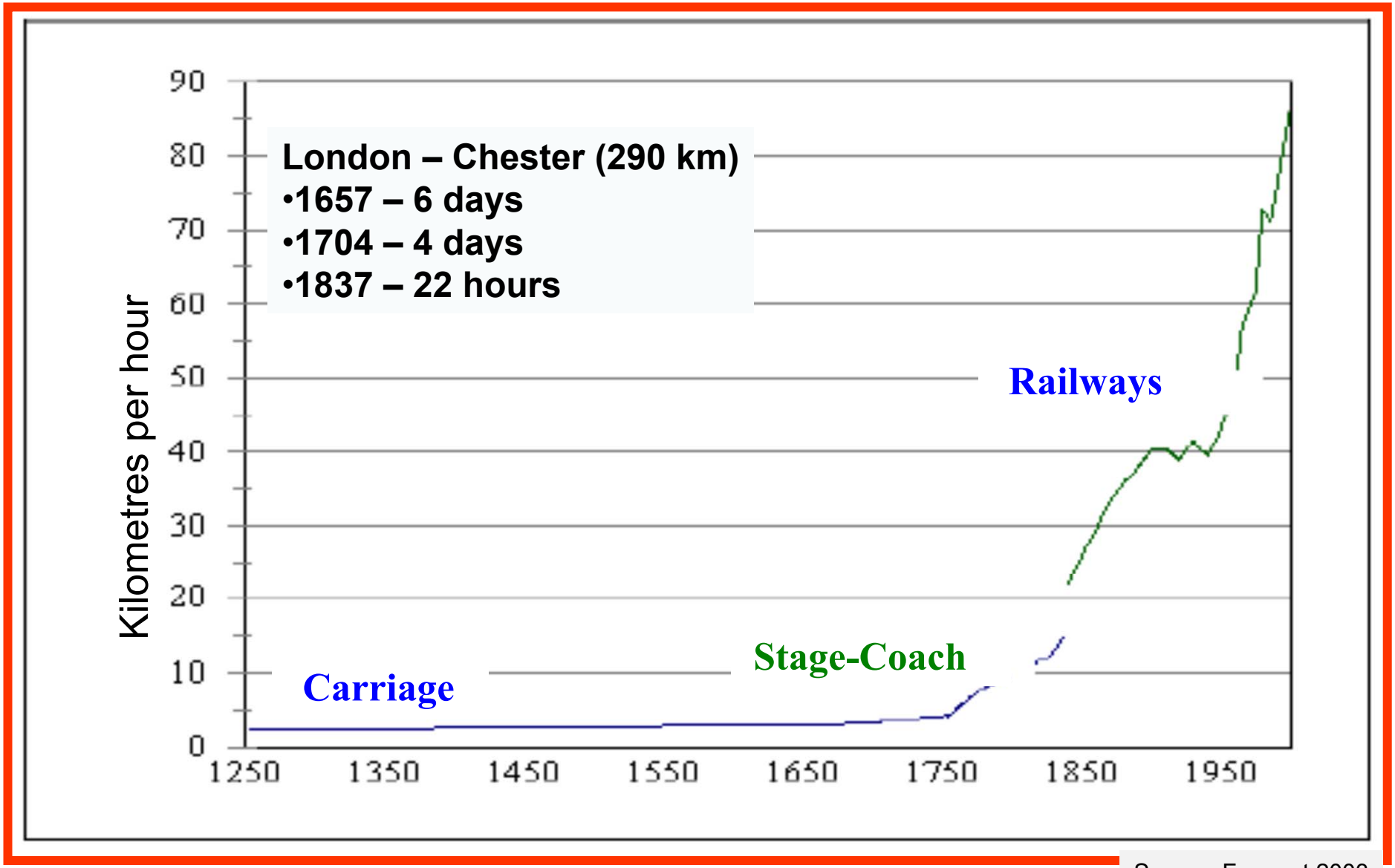
Source: Nakicenovic, 1984.

UK – Replacement within vehicle fleets



The Speed of Transport

(Kilometres per Hour)

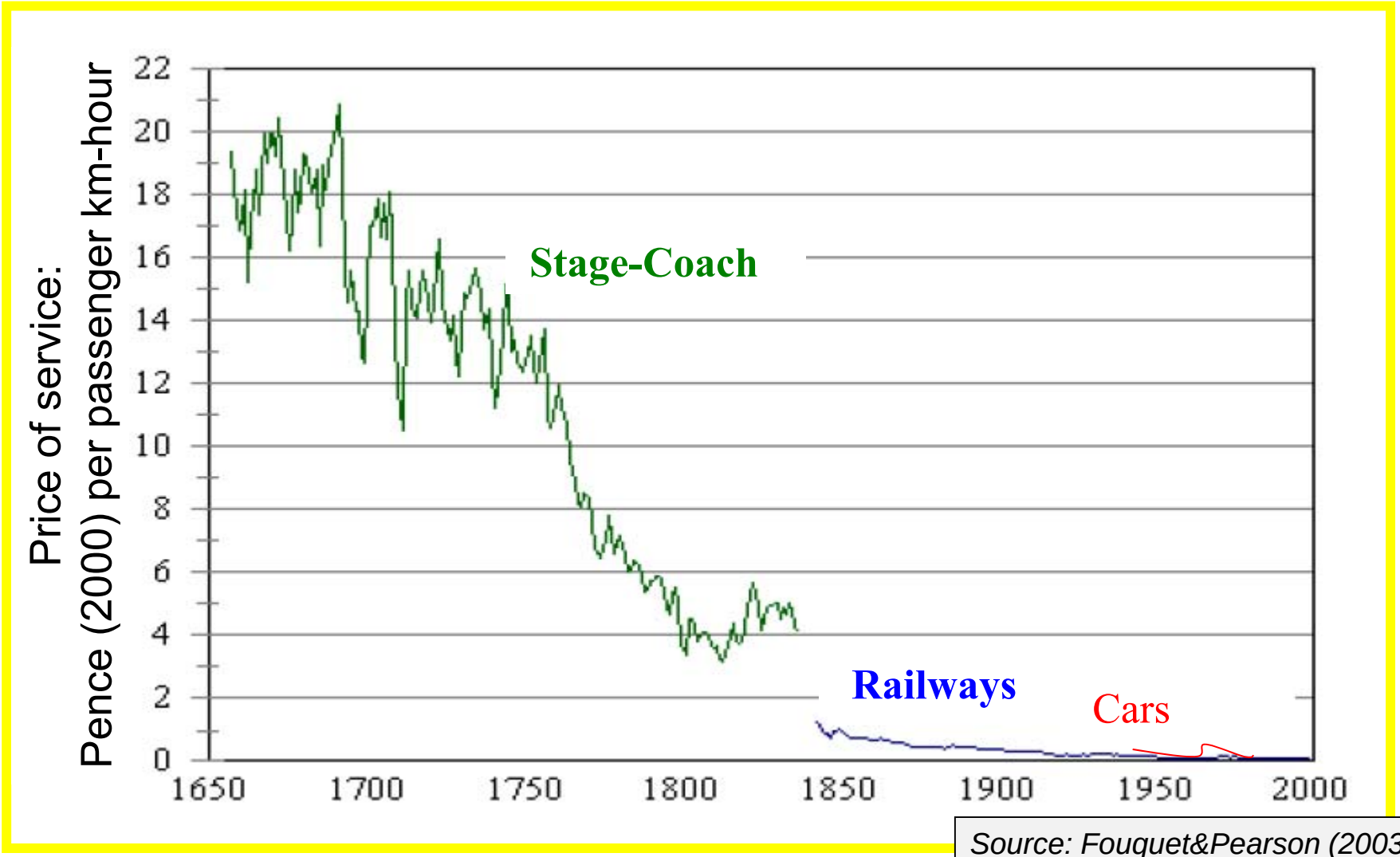


Source: Fouquet,2003

Price of Passenger Transport

(per passenger-kilometer-hour)

The price of service dropped dramatically!



Source: Fouquet&Pearson (2003)

220 000 EURO

hätte ein Arbeiter 1910 für ein neues Auto aufbringen müssen

1910 kostete ein Auto im Schnitt 10 000 Mark. Ein Arbeiter hatte damals ein Jahresgehalt von etwa 1450 Mark – sieben Jahre musste er theoretisch alles sparen, um sich ein Auto leisten zu können. Rund 220 000 Euro sind der heutige Gegenwert von sieben Jahresgehältern. Dafür gibt es einen Ferrari.

247 EURO

kostete 1961 die Auto-Wartung

Für einen Ford Mondeo bis zu einer Laufleistung von 100 000 km betragen die Wartungskosten heute 881 Euro. Vor 50 Jahren waren es für den Vorgänger Ford Taunus umgerechnet 247 Euro – ein Anstieg von 257 Prozent.

7,60 EURO

musste man um 1920 für einen Liter Benzin zahlen

Anfang der zwanziger Jahre kam es in Deutschland zur Hyperinflation. Die Preise stiegen unaufhörlich – Benzin war davon nicht ausgenommen. In der Spitze kostete der Liter 1,90 Mark. Umgerechnet auf die heutige Zeit würde das einem Literpreis von zirka 7,60 Euro entsprechen. Erst nach der Währungsreform Ende 1923 erreichten die Spritpreise wieder ein normales Niveau, das mit unseren Verhältnissen vergleichbar ist.

10 000 EURO

kostete um 1900 ein kompletter Satz Luftreifen

Luftgefüllte Reifen zählten um 1900 zum Zubehör, und der Satz kostete um die 250 Mark. Zu jener Zeit entsprach das im Schnitt mehr als einem Drittel des Jahresgehalts eines Arbeiters. Gäbe es dieses Verhältnis heute noch, müsste man 10 000 Euro für Reifen zahlen.

54 EURO

kostete 1956 eine Fahrt von Stuttgart nach Hamburg

636 EURO

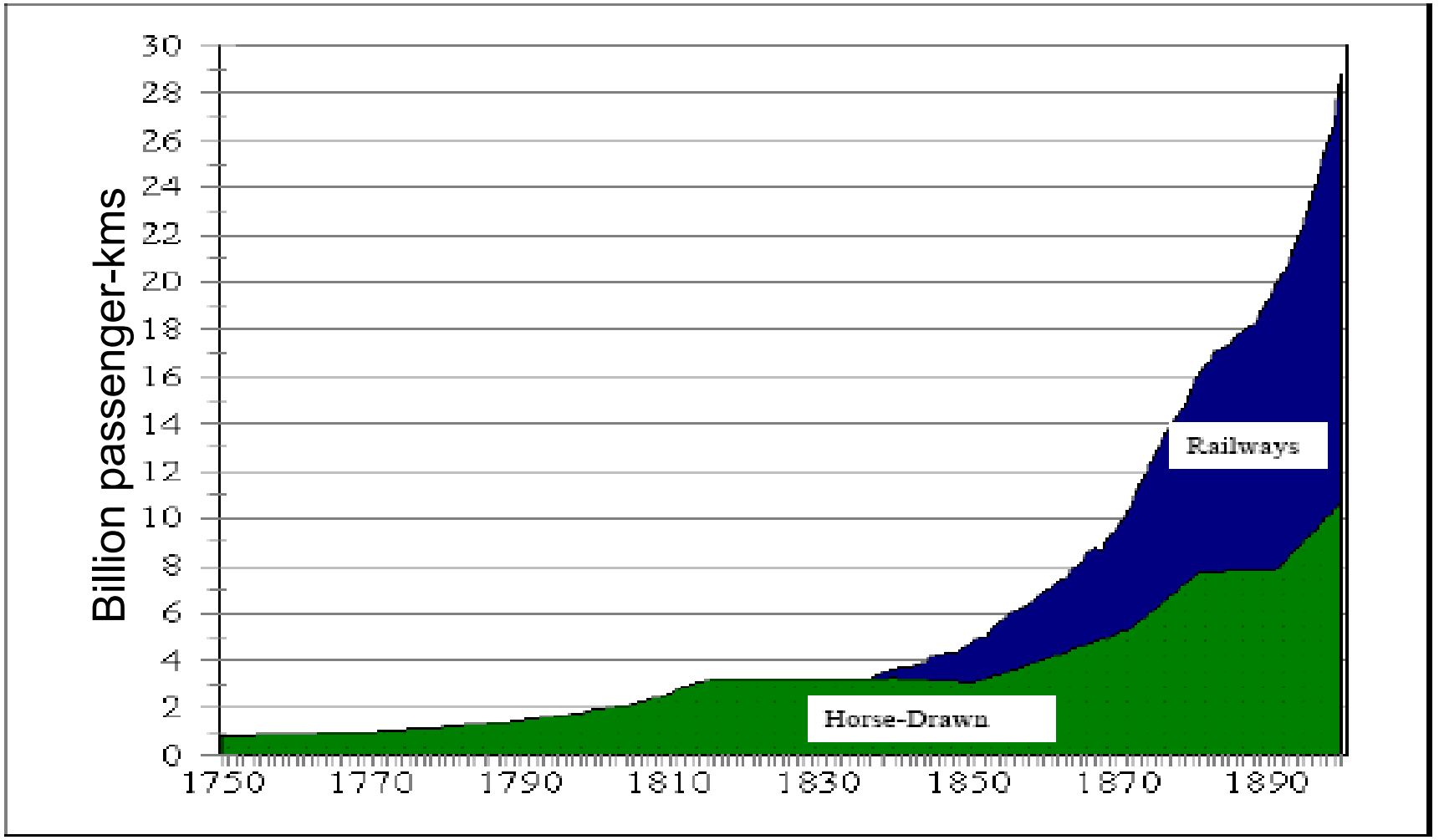
musste man 1930 für die Kfz-Steuer aufbringen

Ostmann, 2011

UK: The Use of Passenger Transport

(per Passenger-Kilometre), 1750-1900

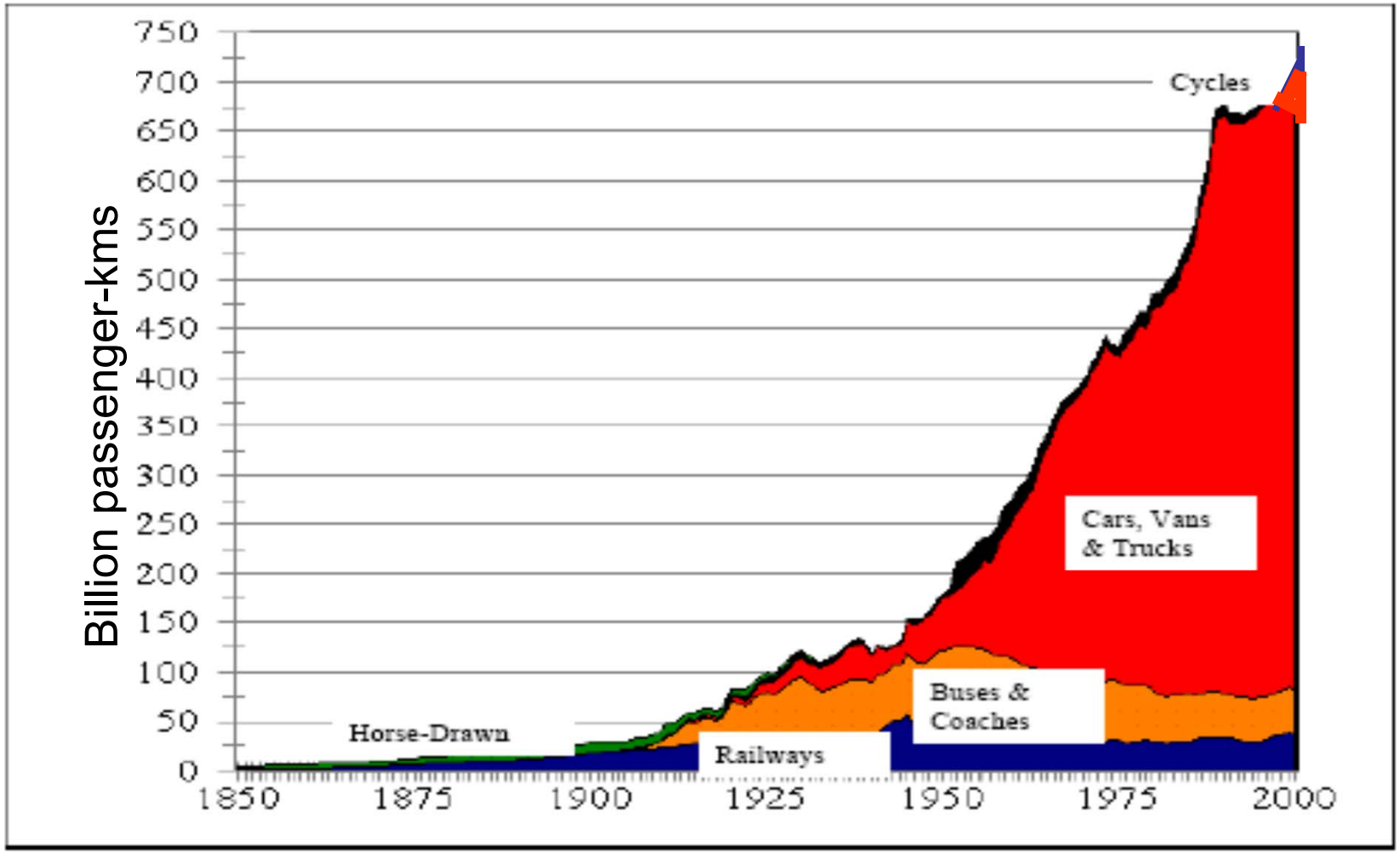
The demand for service



Source: Fouquet,2003

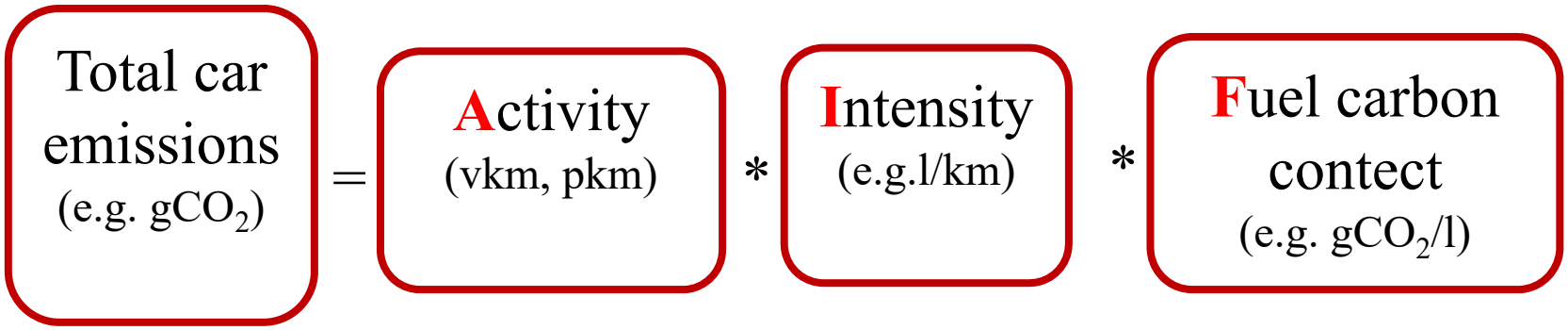
UK: The Use of Passenger Transport

(per Passenger-Kilometre), 1850-2000



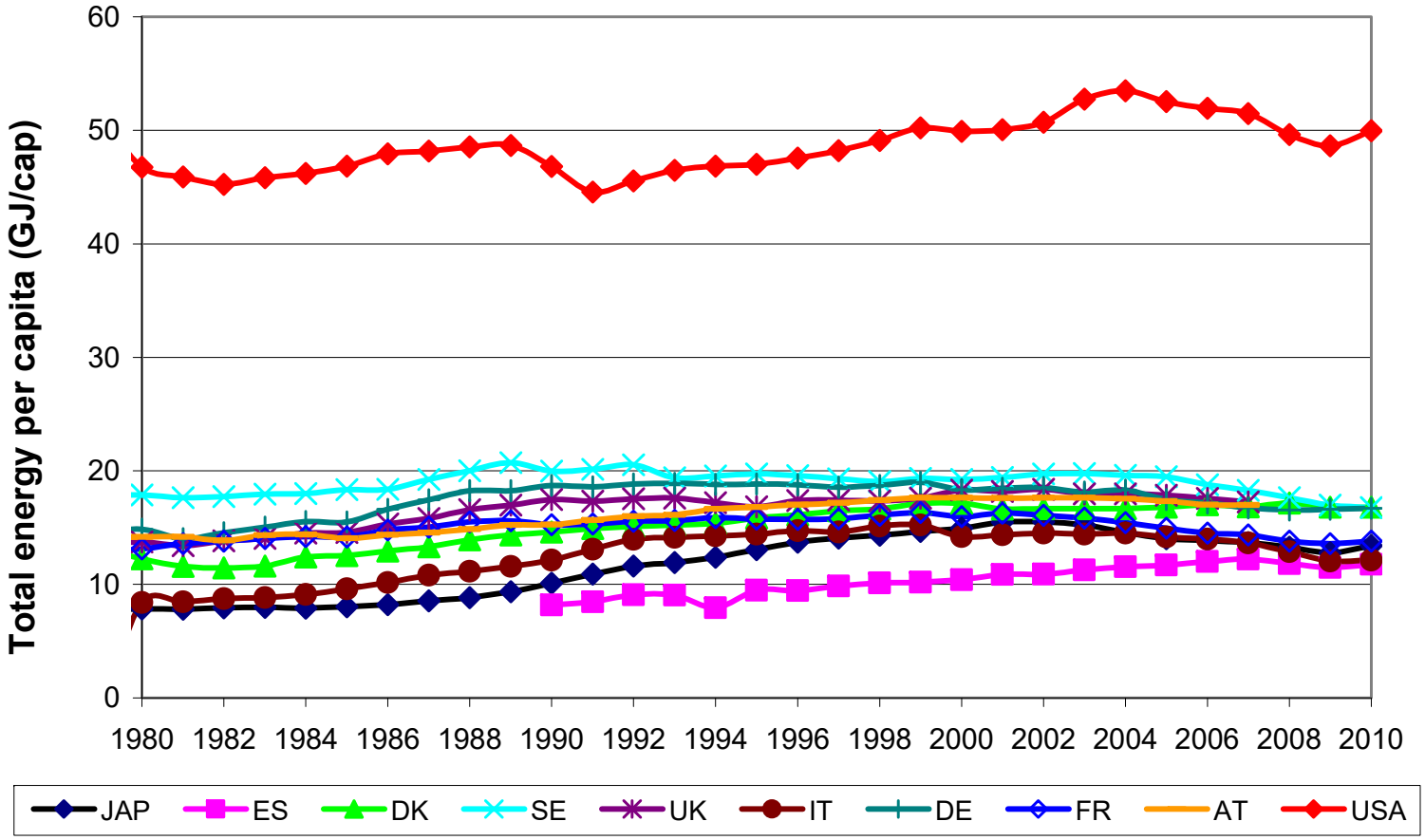
Source: Fouquet,2003

Car emissions



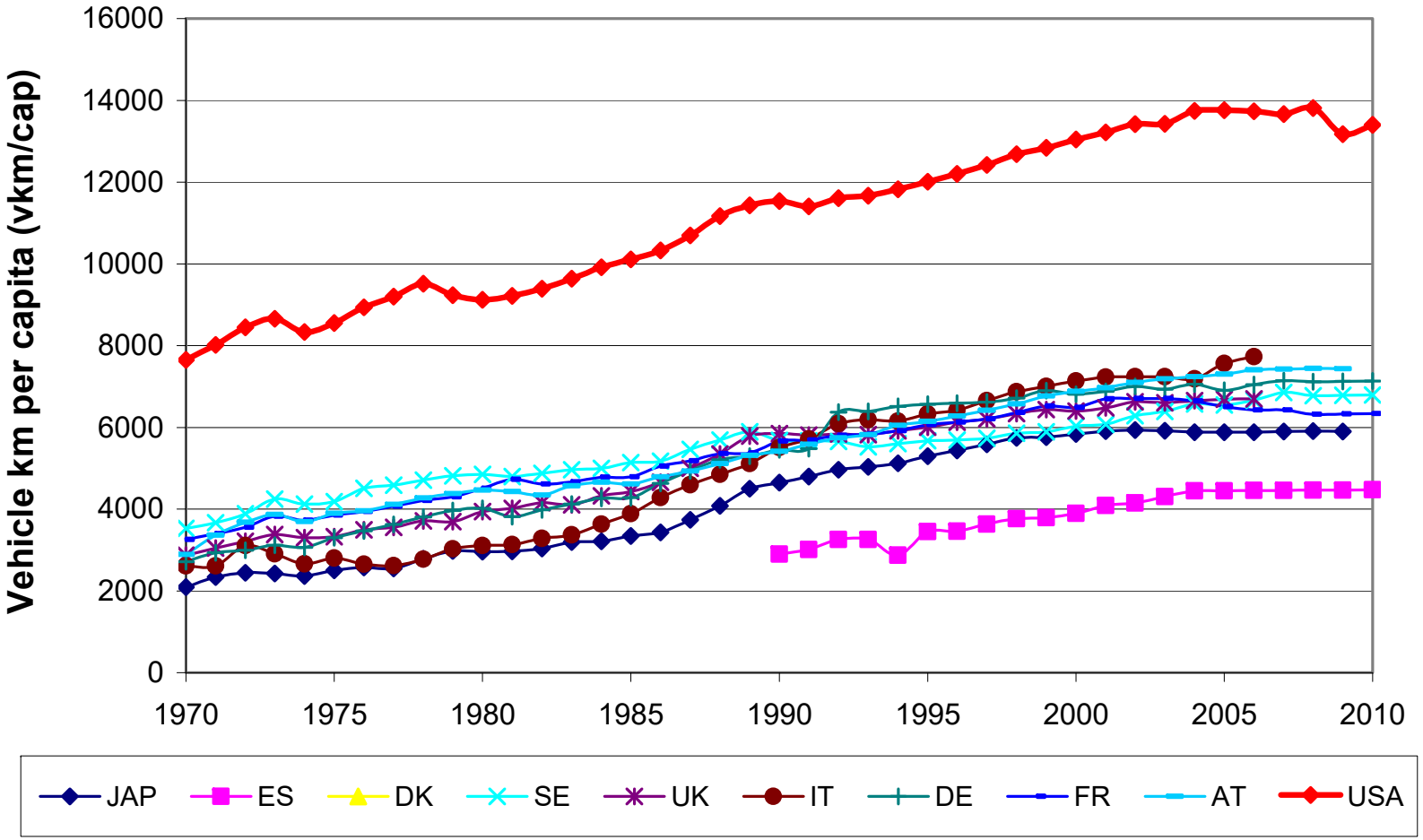
Major indicators

Energy consumption



Development of energy use per capita for passenger cars and household light trucks/SUV

Travel activity



Development of vehicle kilometer per capita

Travel activity

- *Vehicle-kilometers (vkm)*

  vkm = number of vehicles x kilometers per vehicles

- *Passenger-kilometers (pkm)*

  pkm = vkm x occupancy rate

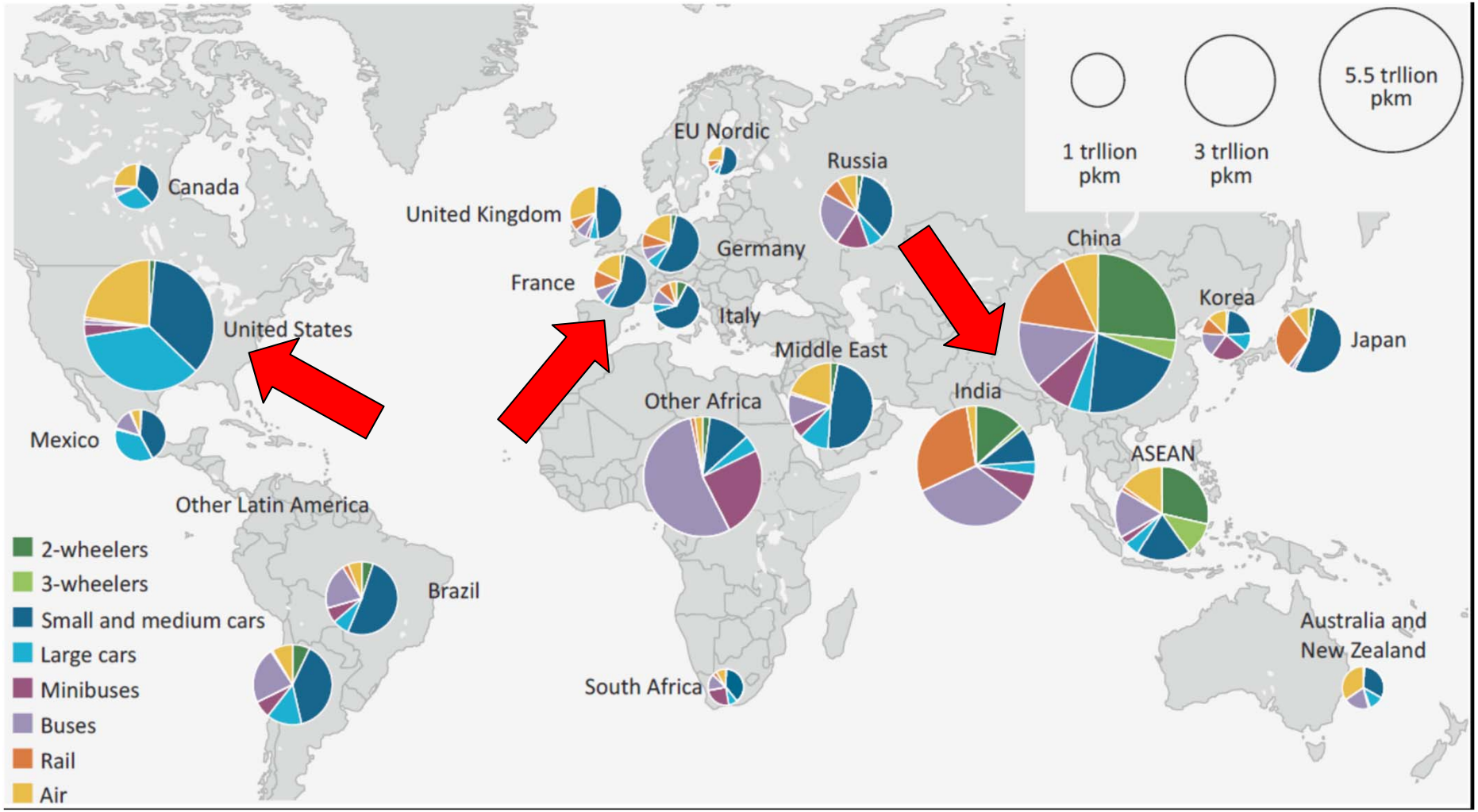
  occupancy rate = number of people / vehicle

Passenger transport activity in 2015, by mode

Modal choices affect final energy demand

Passenger cars dominate in high income countries

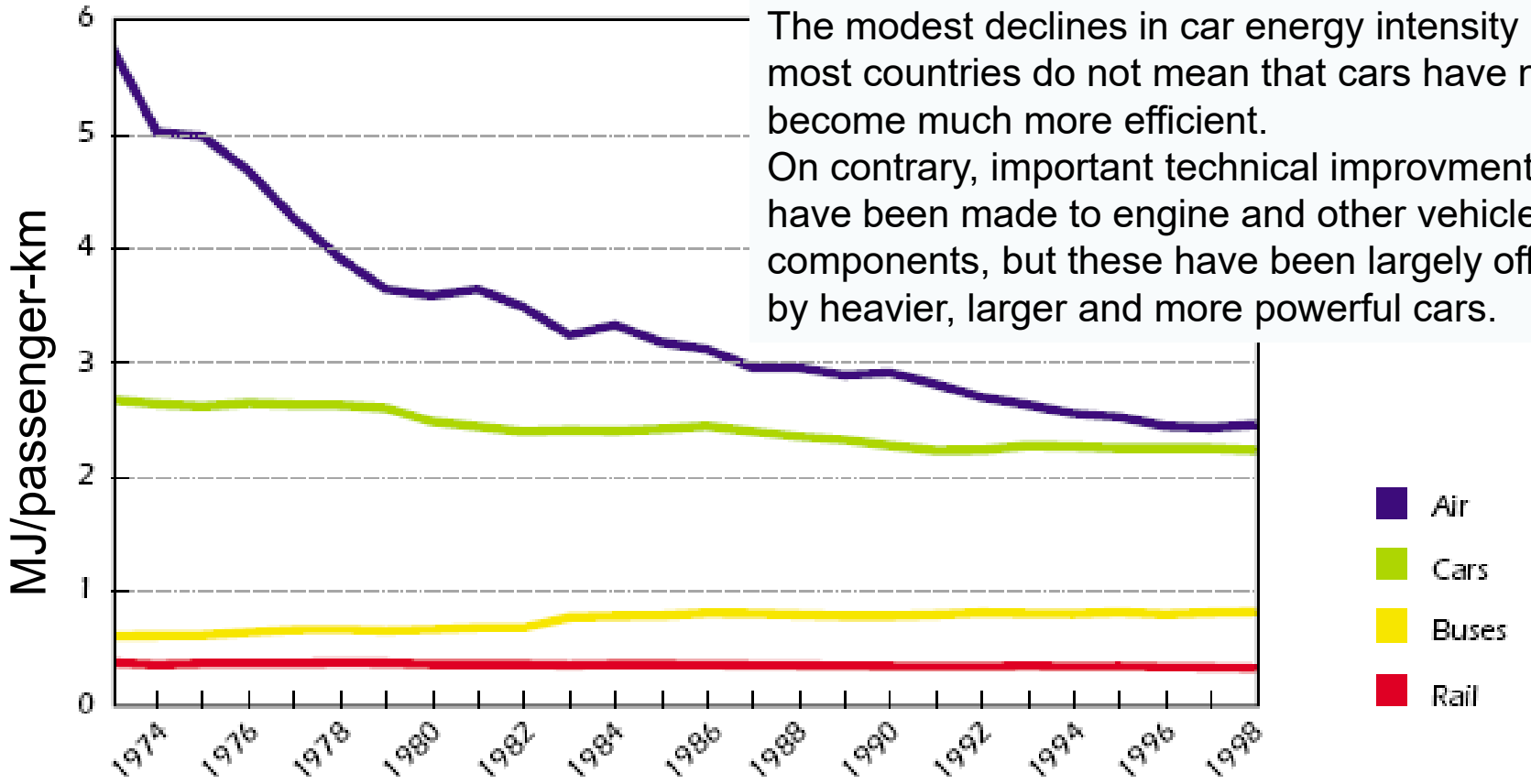
Lower income countries: much larger importance of two wheelers and collective transport modes



Modal Energy Intensities

Energy per Passenger-kilometre by Mode

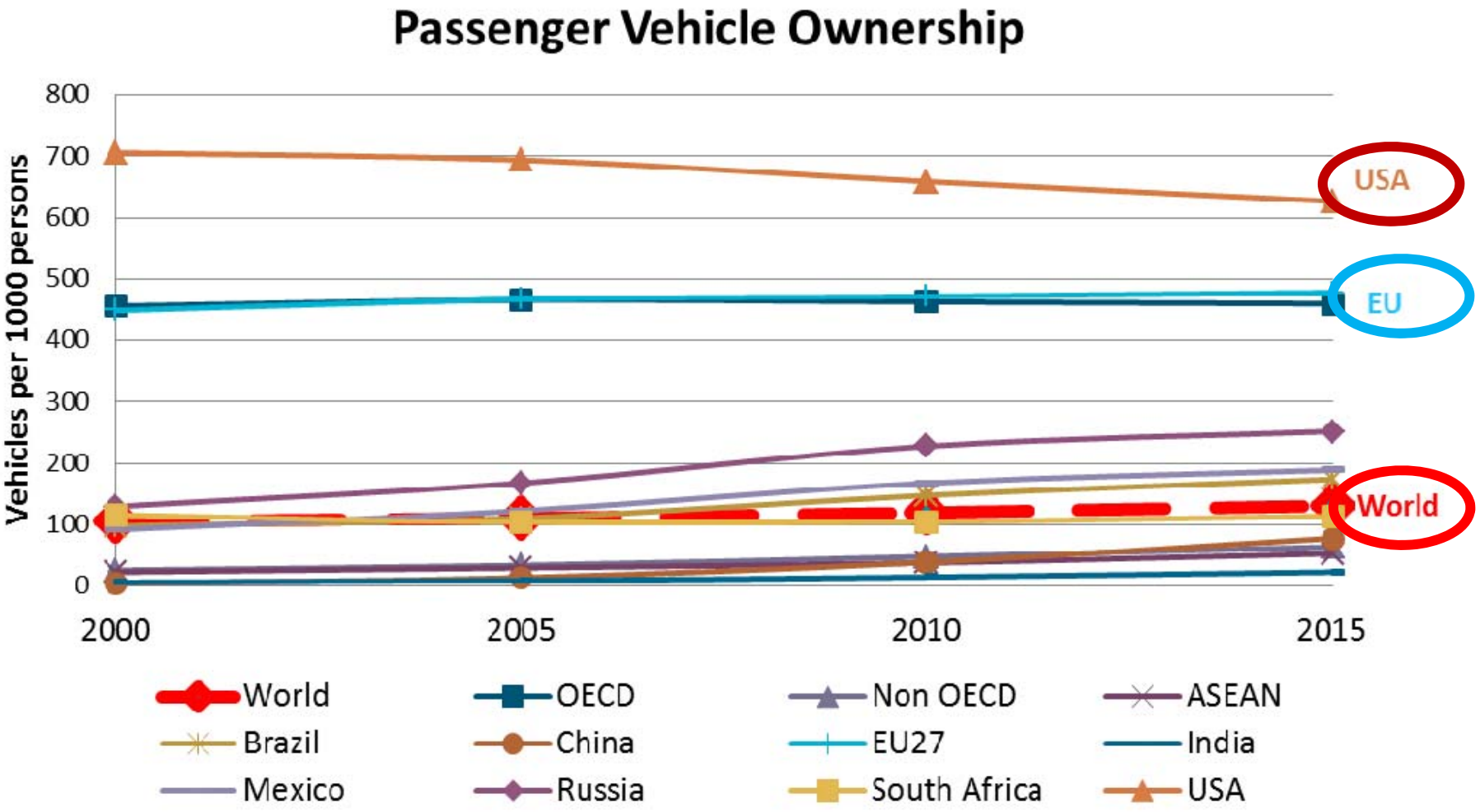
Energy intensity of air travel has declined the most, but remains the most energy intensive mode



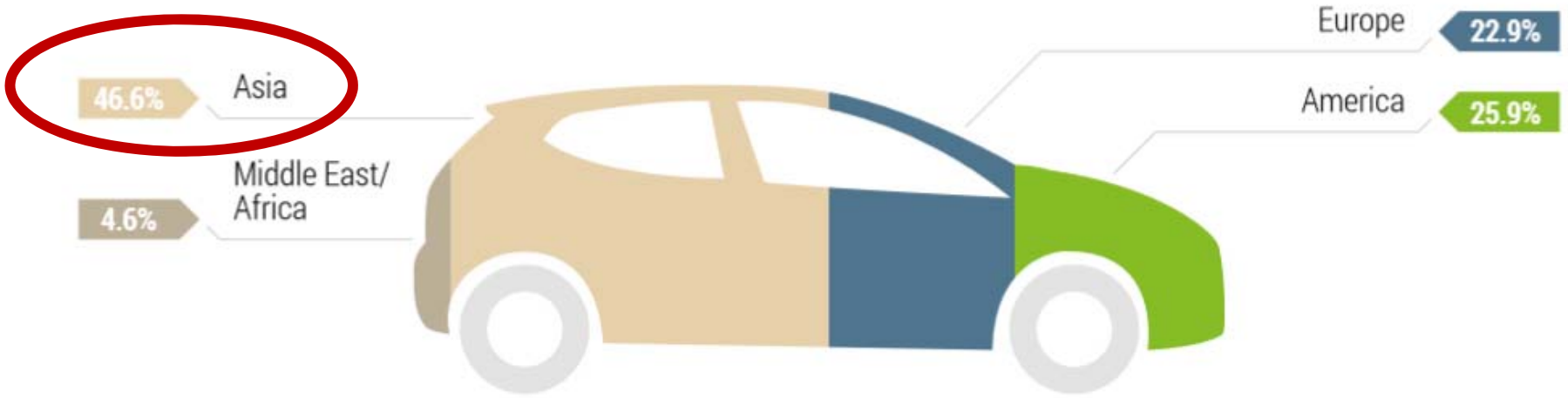
The modest declines in car energy intensity in most countries do not mean that cars have not become much more efficient.
On contrary, important technical improvments have been made to engine and other vehicle components, but these have been largely offset by heavier, larger and more powerful cars.

Source: IEA, 2004

Transport indicators



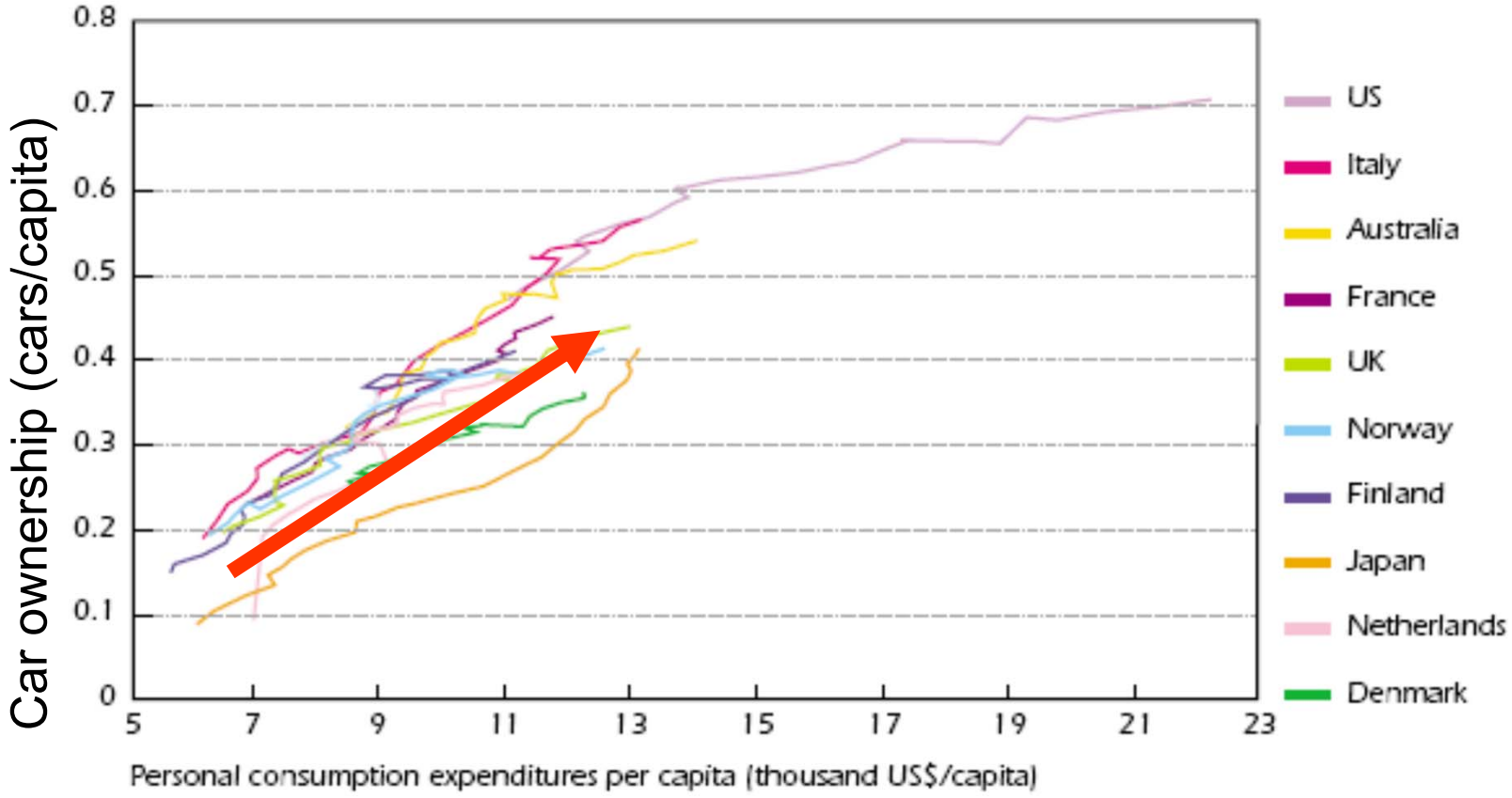
New passenger car registrations, 2018



Car Ownership and Income

Car Ownership per Capita and Personal Consumption Expenditures, 1970 - 2000

The United States leads the way in both car ownership and income



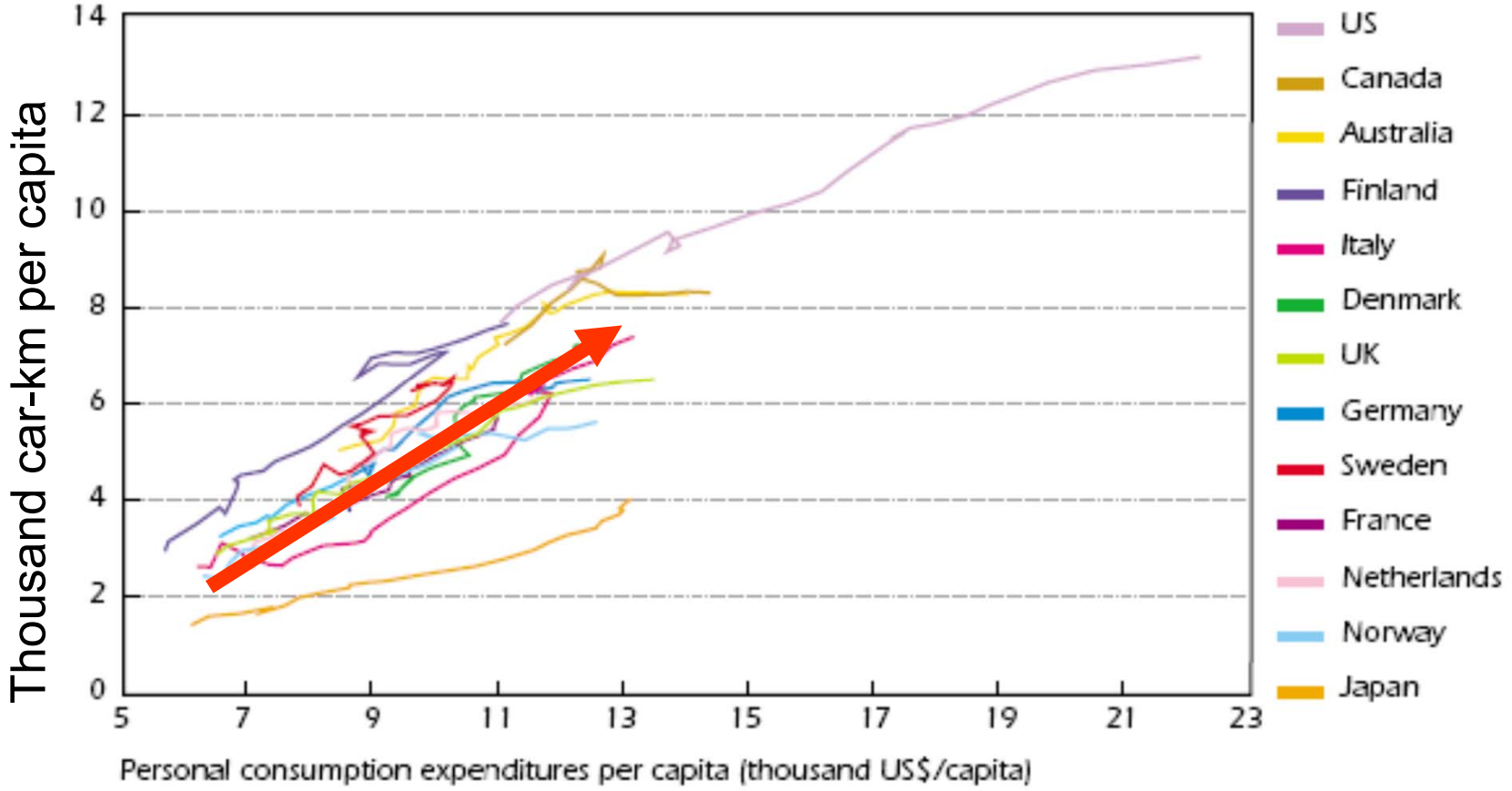
PCE = Income - Savings

Source: IEA, 2004

Car Travel and Income

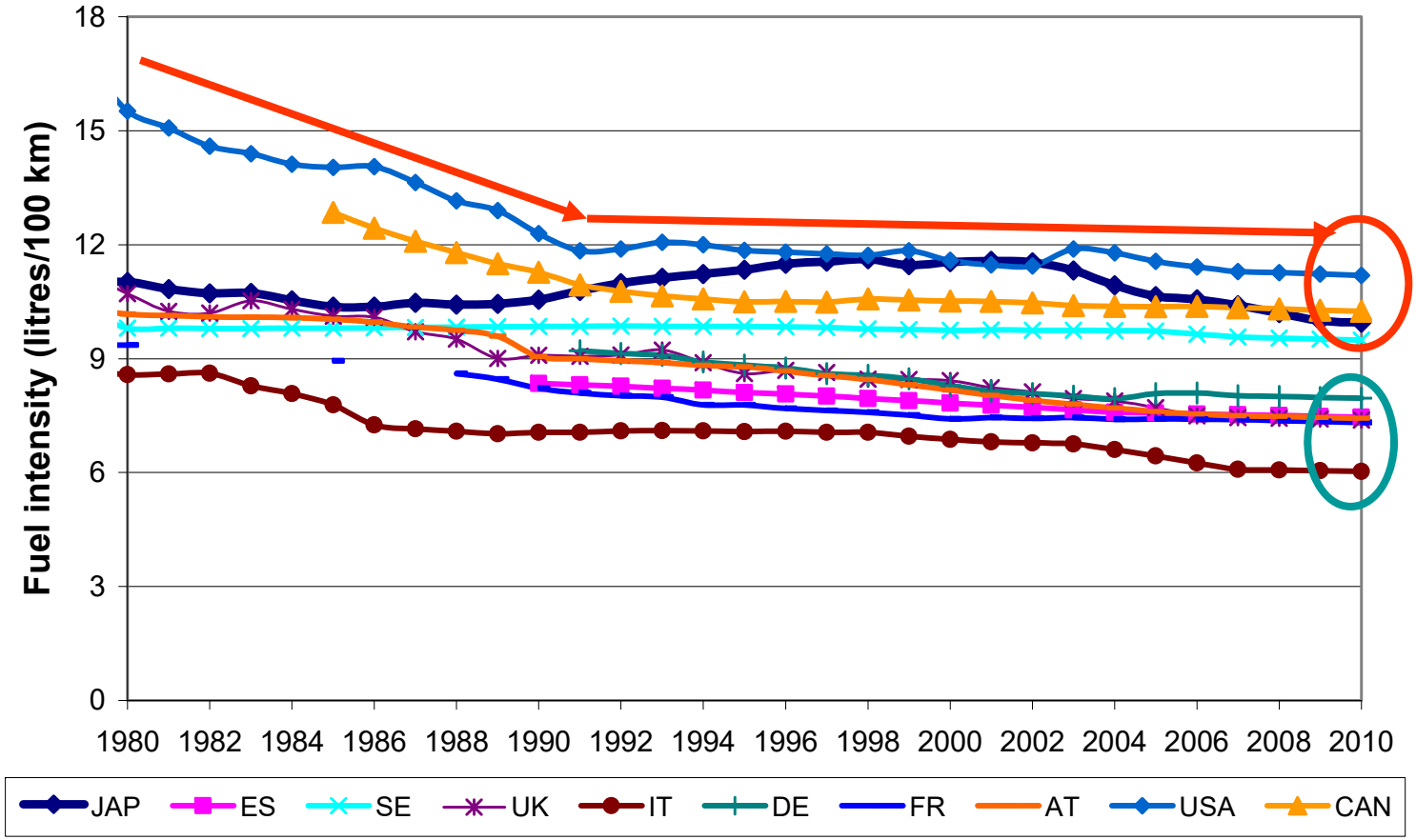
Car-kilometres per Capita and Personal Consumption Expenditures, 1970-2000

The trend for car travel is quite similar to car ownership



Source: IEA, 2004

Fuel intensity



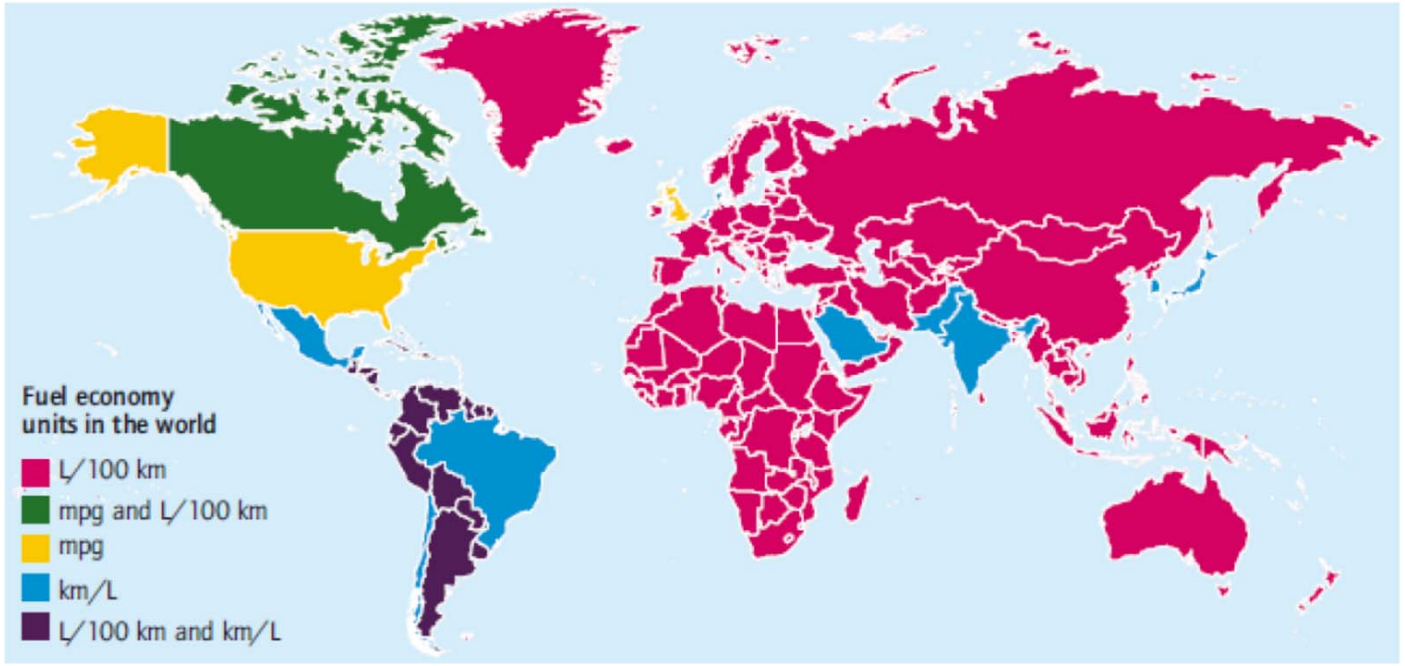
Average on road fuel intensity of stock of cars and household light truck fleet (gasoline equivalent)

Energy intensity

- *Energy intensity - energy needed to move a vehicle*

Measure as:

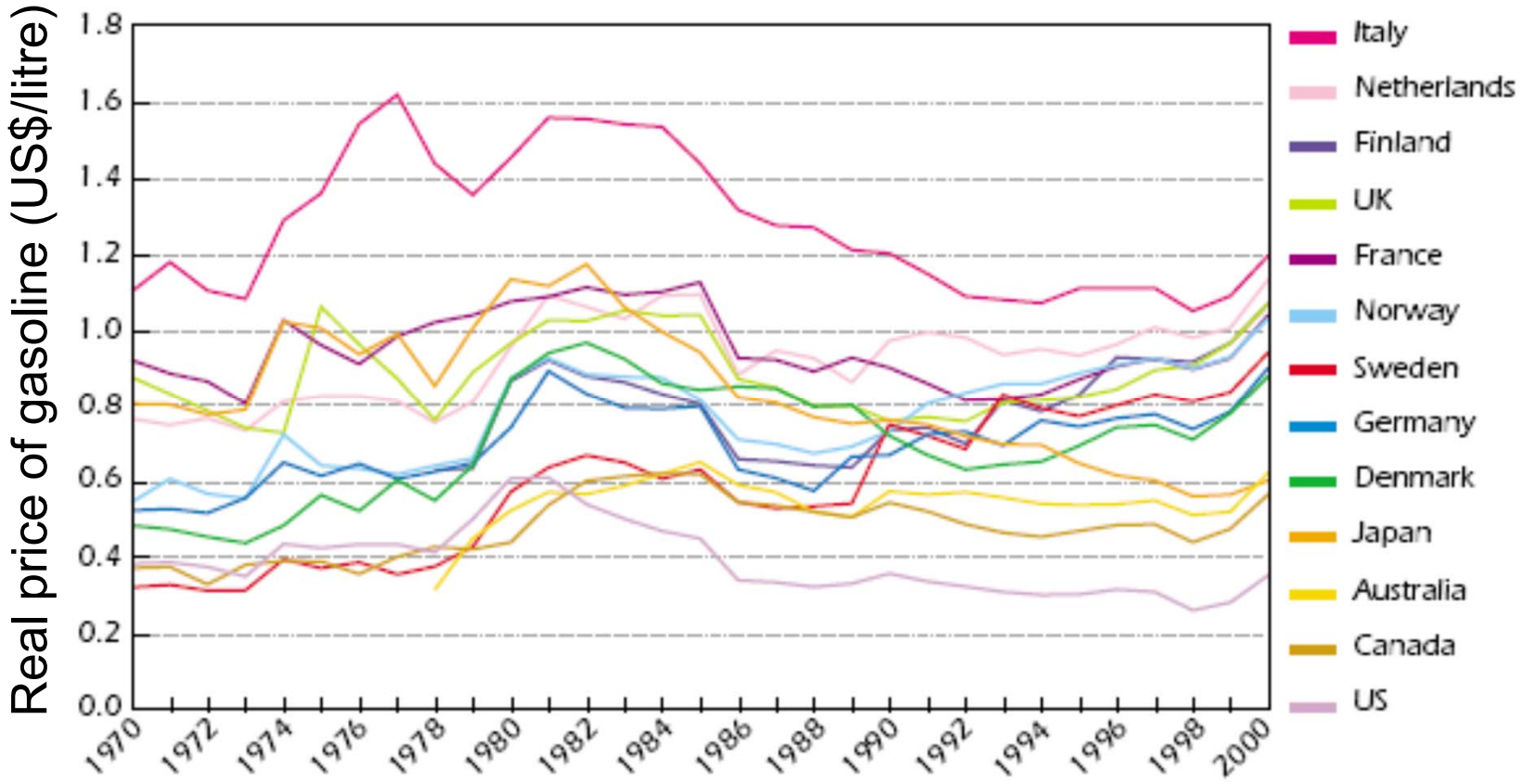
- *Liters/100 km (e.g. Europe)*
- *km/liters (e.g. Japan)*
- *MPG (miles per gallon) (e.g. US)*



Gasoline Prices

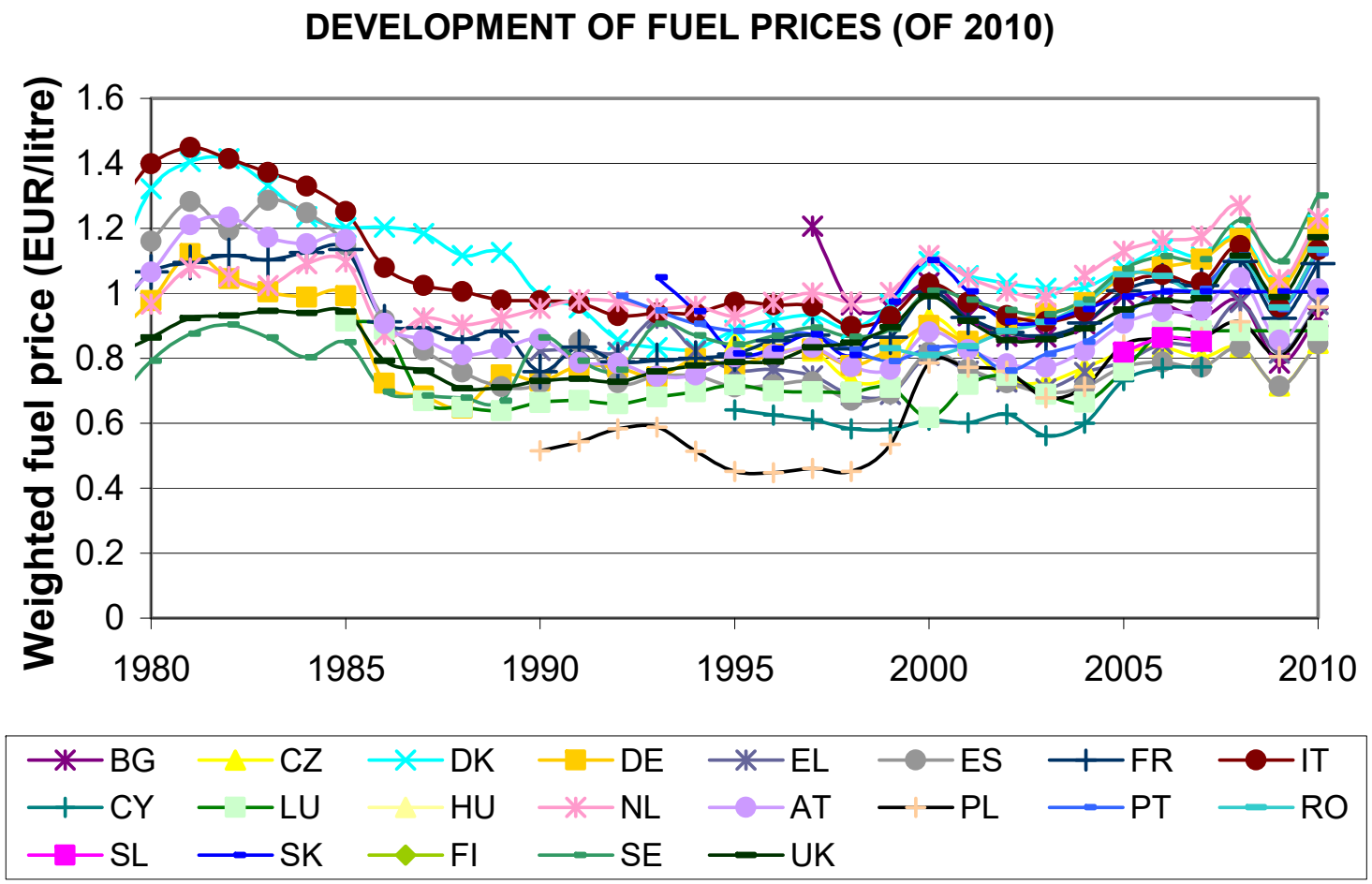
Trends in Retail Gasoline Prices in Real Terms, Including Taxes

Gasoline prices have varied considerably both over time and across IEA countries



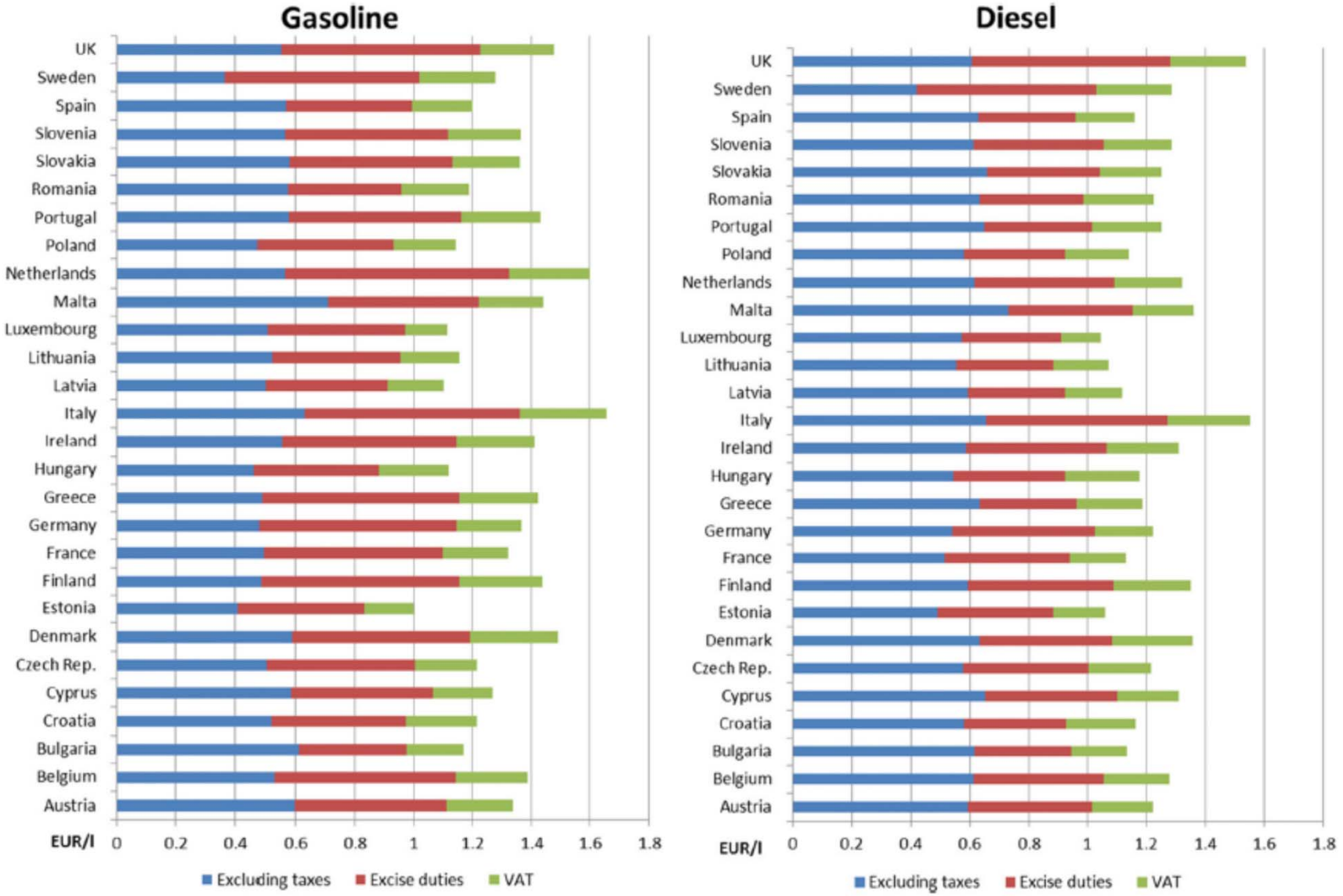
Source: IEA, 2004

Development of fuel prices



Weighted fuel prices (including all taxes) for EU countries 1980 – 2010
(in prices of 2010, numbers for 2010 preliminary) (Source: EEP; IEA, 2010)

Price structure of gasoline and diesel

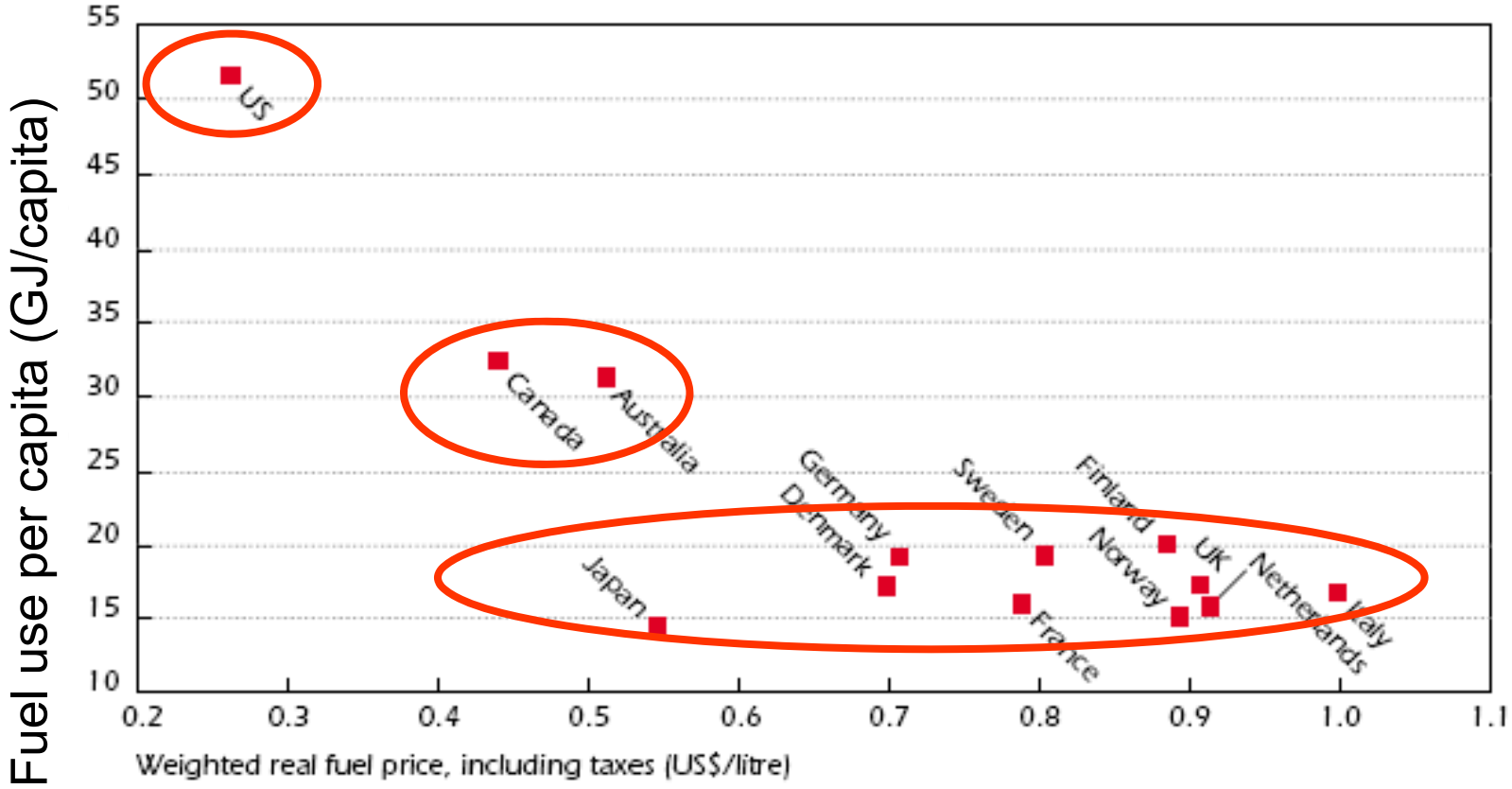


Composition of gasoline and diesel prices including taxes (EEP, 2014) Status: 16 December 2014

Fuel Use per Capita versus Fuel Prices

Car Fuel Use per Capita versus Average Fuel Price, 1998

Energy use for cars is much higher in countries with low fuel prices

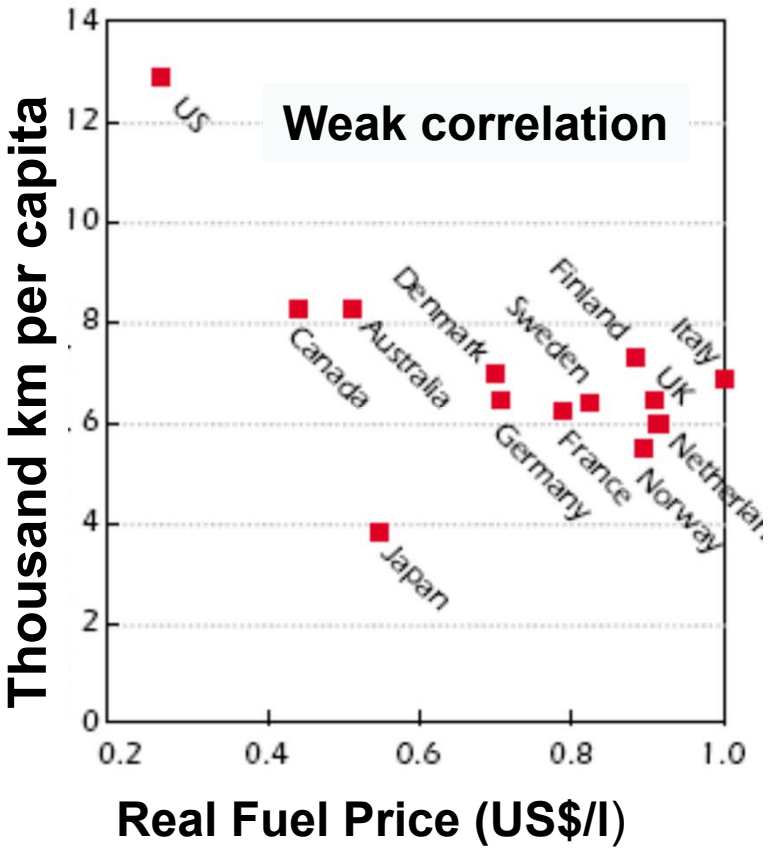


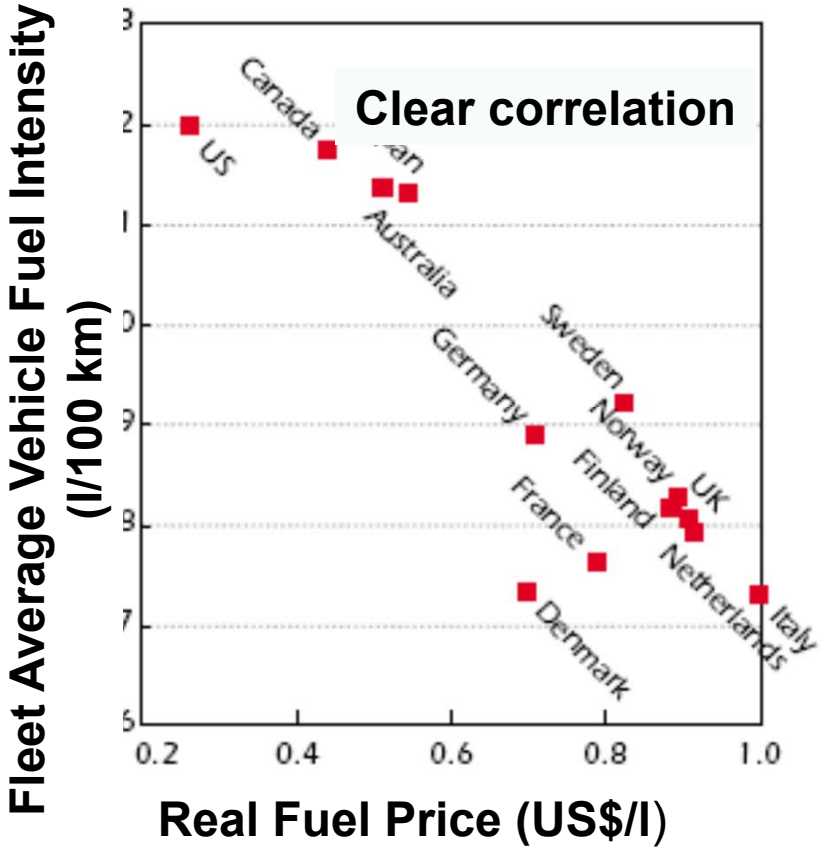
Source: IEA, 2004

Vehicle Travel and Intensities versus Fuel Prices

Passenger Car Travel per Capita and Car Fuel Intensity versus Average Fuel Price, 1998

Higher fuel prices correlate with lower vehicle fuel intensity and lower travel per capita, though the travel effect is fairly weak

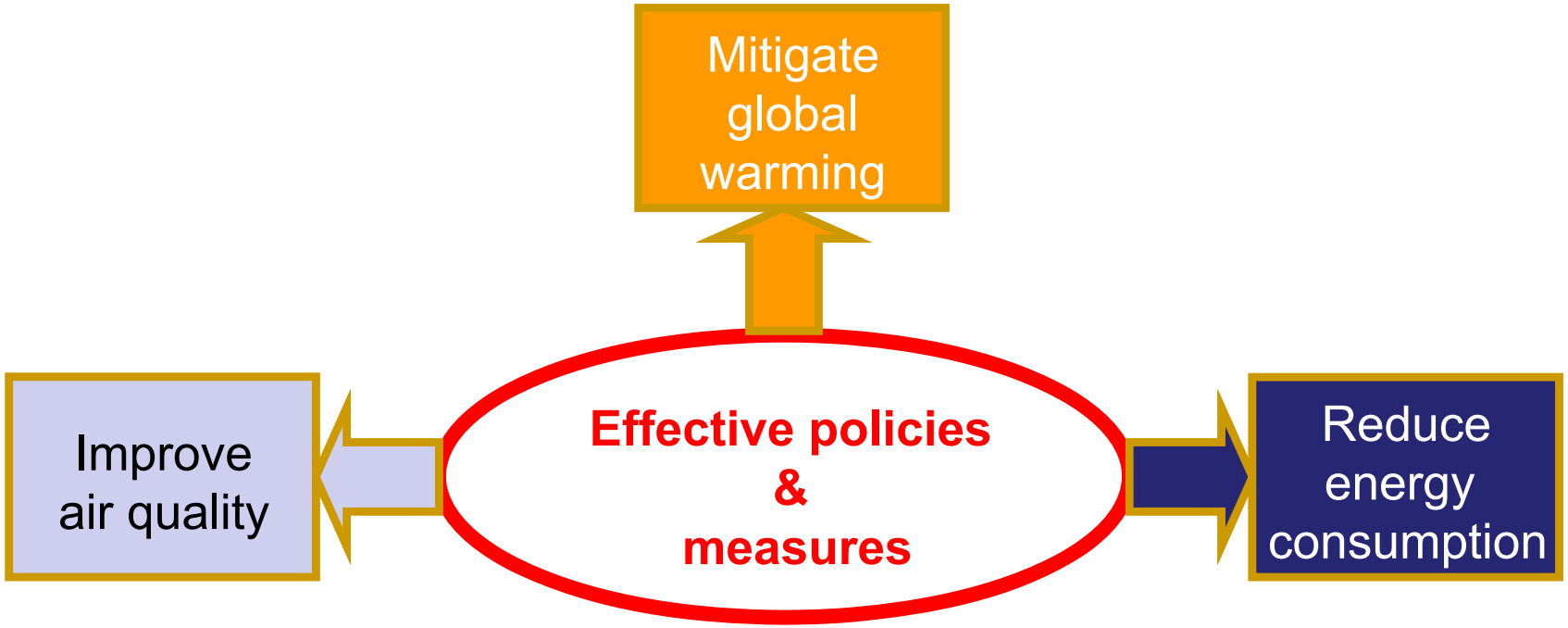




Source: IEA, 2004

- Passenger transport is almost exclusively based on petroleum products. Growth in passenger travel has been the biggest contributor to increased oil demand.
- Changes in passenger transport energy use, as well as its components (travel activity and energy intensity), are related to income growth and changes in fuel prices, among other factors.
- Countries with relatively high fuel prices tend to have lower average vehicle energy intensities and fuel use than countries where fuel prices are low.
- Increases in car ownership and travel levels are closely related to income growth. Together, these relationships help account for large differences in transport energy use per capita among countries.

The challenges for EU climate and energy policies



Alternatives

- Biofuels
- Electricity and electric vehicles
- Hydrogen and fuel cells

Alternative fuels: Biofuels

Biofuels

…fuels produced from biomass

History of biofuels

- 1826 - Samuel Morey developed an engine that ran on ethanol and turpentine.
- 1860 - German engine inventor Nicholas Otto used ethanol as the fuel in one of his engines.
- In 1900, Rudolf Diesel demonstrated his compression ignition engine at the World's Exhibition in Paris. In that prototype engine he used peanut oil, the first biodiesel.
- Until the 1940s, biofuels were seen as viable transport fuels and bioethanol blends were commonly used in the US, Europe and other regions
- Further development of bioethanol stopped after the Second World War - petroleum-derived fuel became cheap
- During the oil crisis in 1970s, many countries showed renewed interest in production of commercial biofuels

History of biofuels

- Brazil started to produce ethanol at a large scale... mandatory blending since 1977… the government incentivized the development of 100% ethanol fuel vehicles and the associated infrastructure

- During the late 1990s, the US and many nations in Europe developed policies in support of domestic biofuel industries…supply security

- The interest in biofuels further increased in the past decade with the development of policies on climate change mitigation and strategies to reduce GHG emissions from the transport sector. More than 60 countries - biofuel programmes and set targets for blending biofuels

- around 4% to transportation fuels globally

Biofuels

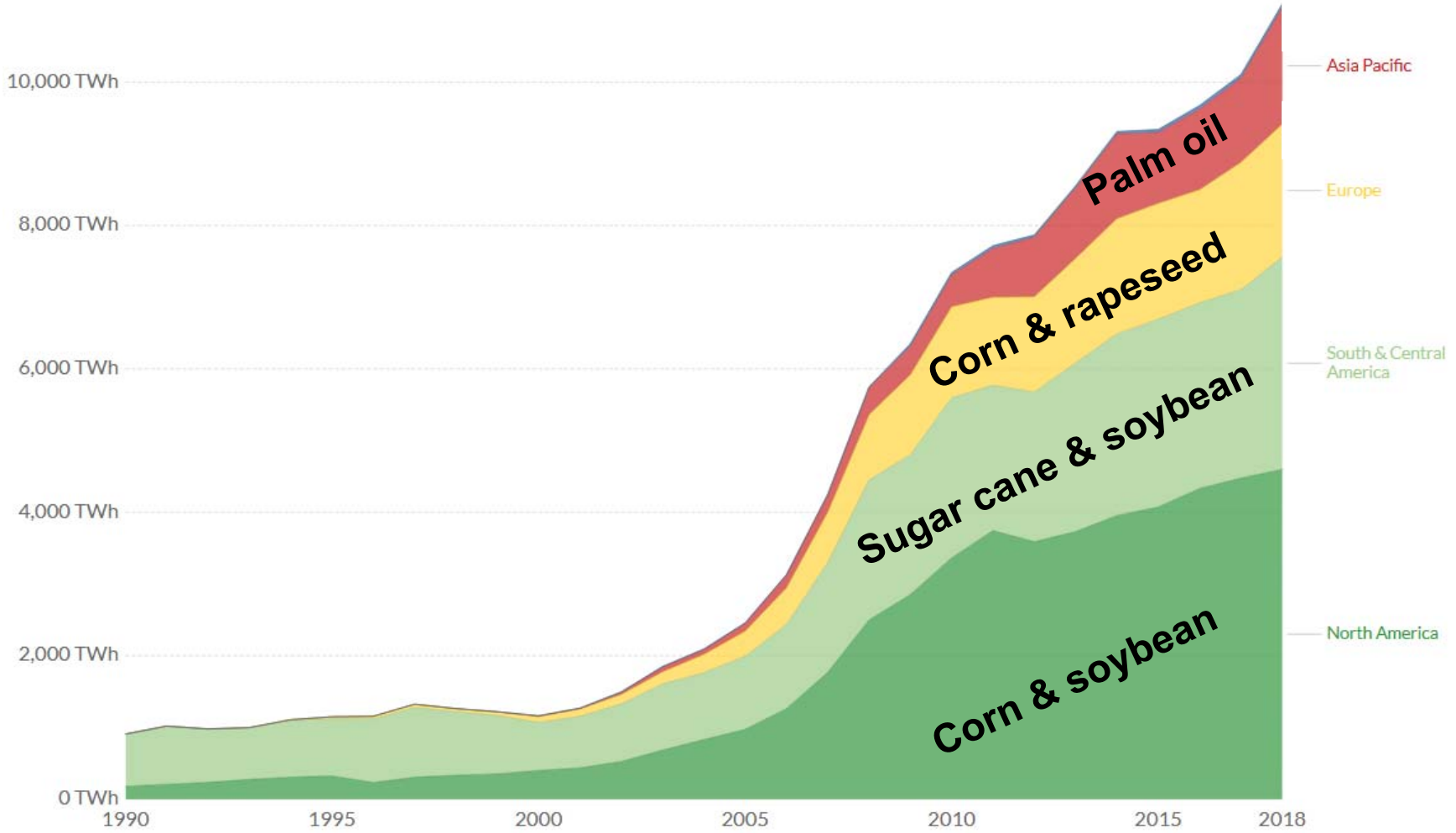
Mature biofuels
1st generation biofuels

Immature biofuels
2nd generation biofuels
(from lignocellulose)

Biofuels in labour stage
3rd generation biofuels
(from algae)

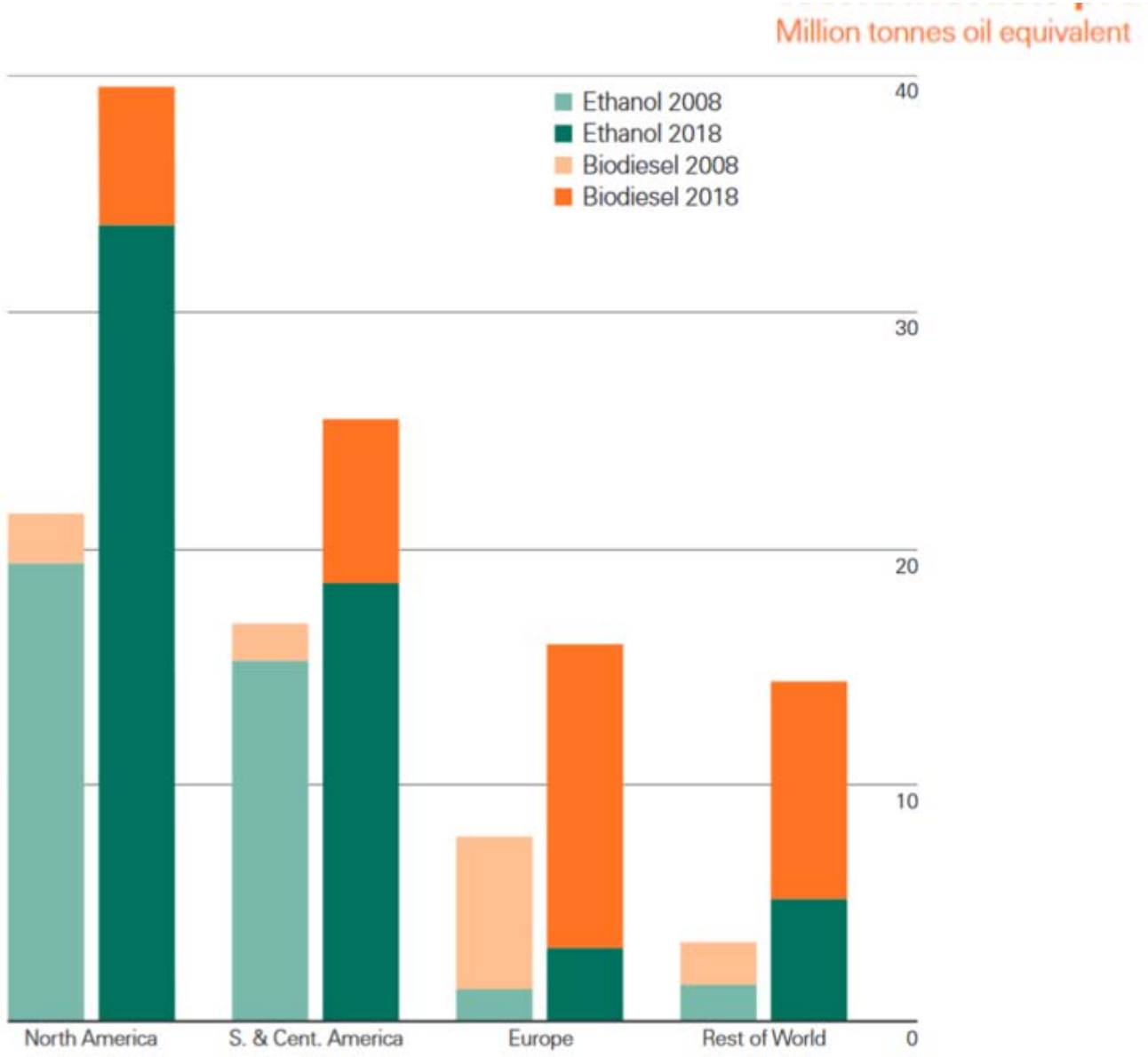
Long term possibility
4th generation biofuels
(from genetically manipulated feedstocks)

Biofuels production by region



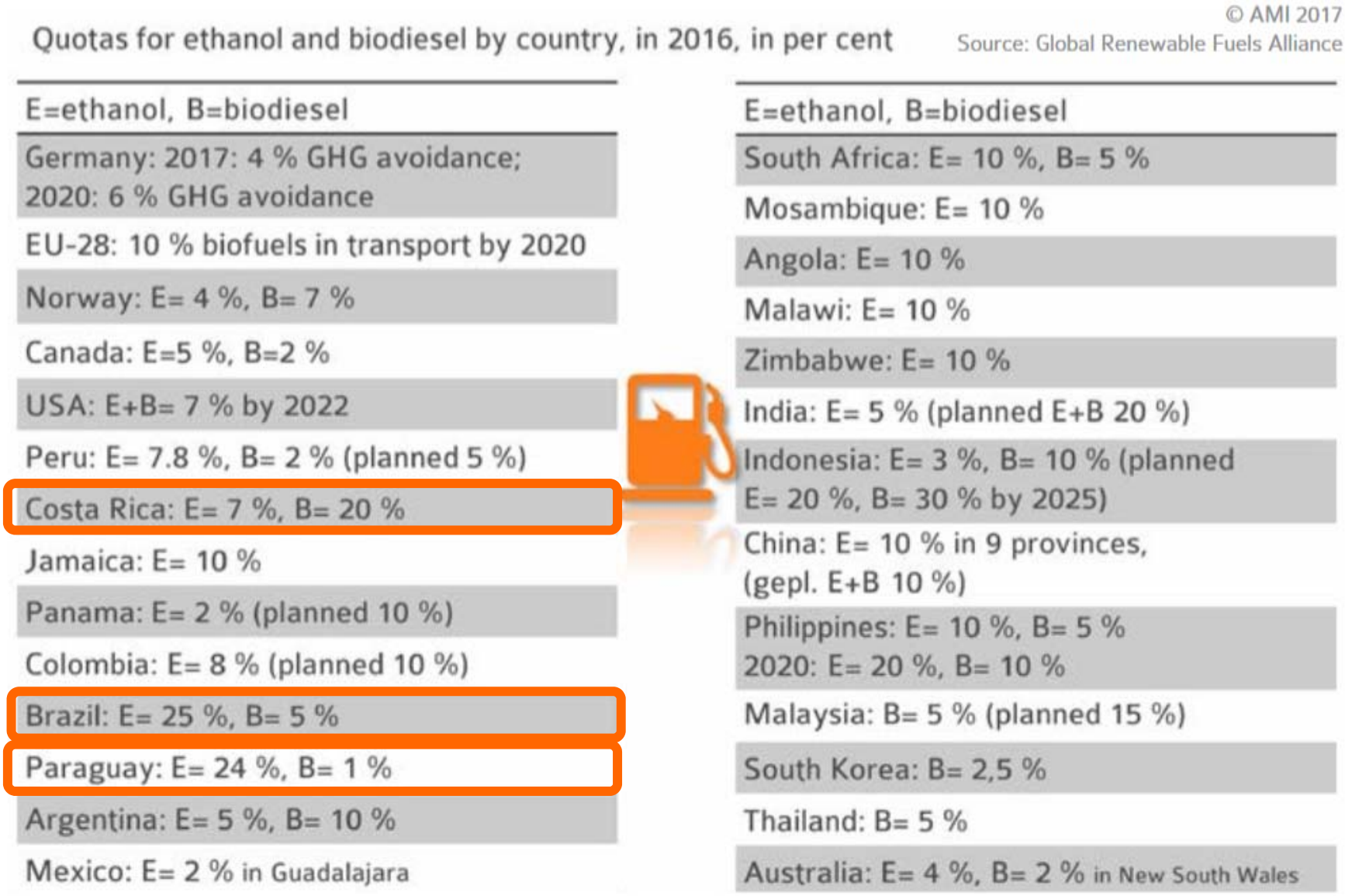
BP, 2019

World biofuels production



BP, 2019

Quotas


Quotas for ethanol and biodiesel by country, in 2016, in per cent
© AMI 2017
Source: Global Renewable Fuels Alliance
E=ethanol, B=biodiesel
Germany: 2017: 4 % GHG avoidance; 2020: 6 % GHG avoidance
EU-28: 10 % biofuels in transport by 2020
Norway: E= 4 %, B= 7 %
Canada: E=5 %, B=2 %
USA: E+B= 7 % by 2022
Peru: E= 7.8 %, B= 2 % (planned 5 %)
Costa Rica: E= 7 %, B= 20 %
Jamaica: E= 10 %
Panama: E= 2 % (planned 10 %)
Colombia: E= 8 % (planned 10 %)
Brazil: E= 25 %, B= 5 %
Paraguay: E= 24 %, B= 1 %
Argentina: E= 5 %, B= 10 %
Mexico: E= 2 % in Guadalajara
E=ethanol, B=biodiesel
South Africa: E= 10 %, B= 5 %
Mosambique: E= 10 %
Angola: E= 10 %
Malawi: E= 10 %
Zimbabwe: E= 10 %
India: E= 5 % (planned E+B 20 %)
Indonesia: E= 3 %, B= 10 % (planned E= 20 %, B= 30 % by 2025)
China: E= 10 % in 9 provinces, (gepl. E+B 10 %)
Philippines: E= 10 %, B= 5 % 2020: E= 20 %, B= 10 %
Malaysia: B= 5 % (planned 15 %)
South Korea: B= 2,5 %
Thailand: B= 5 %
Australia: E= 4 %, B= 2 % in New South Wales

EU policy

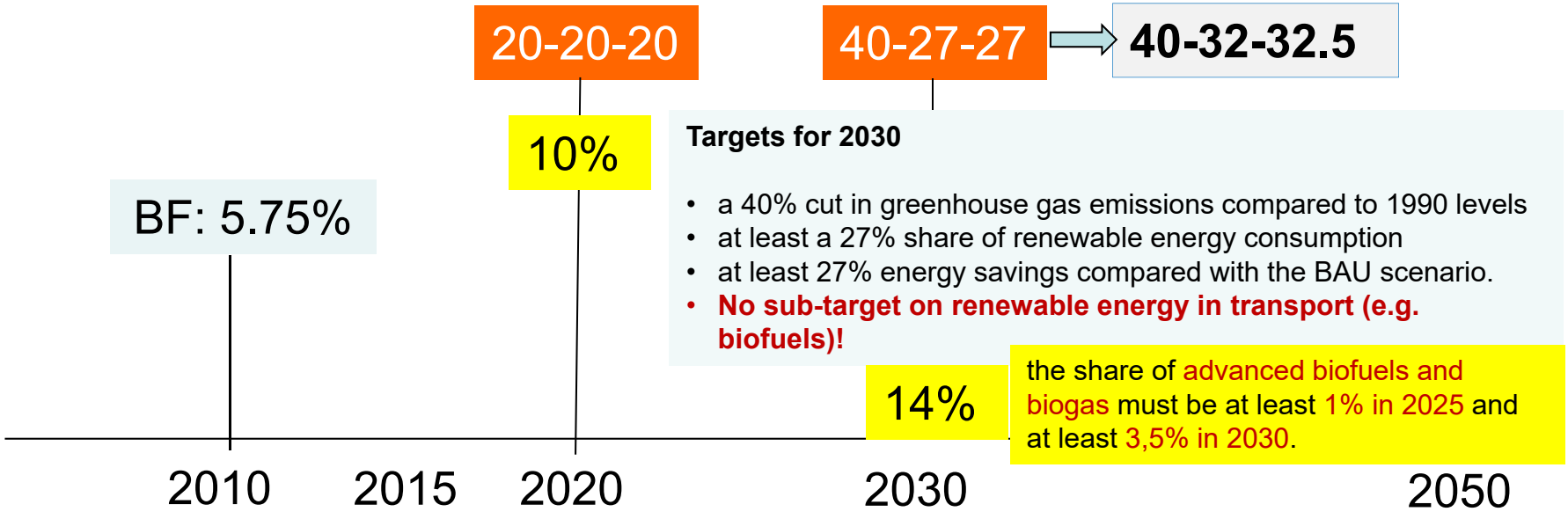
EU Biofuels Directive: Originally Directive **2003**/30/ EC, later amended by Directive 2009/28/EC (see 'EU Renewable Energy Directive'). It stipulated implementation of national measures by member states aimed at replacing 5.75% of all transport fossil fuels (petrol and diesel) with biofuels.

EU Renewable Energy Directive (RED): Directive **2009**/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. The RED requires member states to ensure that 10% of the energy used in transport is from renewable sources by 2020.

EU Fuels Quality Directive (FQD): Directive 98/70/ EC (as amended), requiring suppliers to reduce the lifecycle greenhouse gas intensity of transport fuels and introducing sustainability criteria for biofuels.

EU ILUC Directive: Directive **2015**/1513 amends the Renewable Energy Directive and the Fuel Quality Directive to take account of the effect of indirect landuse change (ILUC) and aims to encourage the transition away from first generation biofuels.

EU policies and targets



New legislation approved by European Parliament on 28 April 2015

- **Cap of 7% on the contribution (to 2020 targets) of biofuels produced from 'food crops'** to mitigate ILUC emissions
- **No public support** for food crop based biofuels post 2020

ICE -50% in city

20% GHG (2008)

No ICE in city

60% GHG (1990)

Transport White Paper

New challenges / risks

+ Reduction of GHG emissions

+ Energy security

+ Rural development

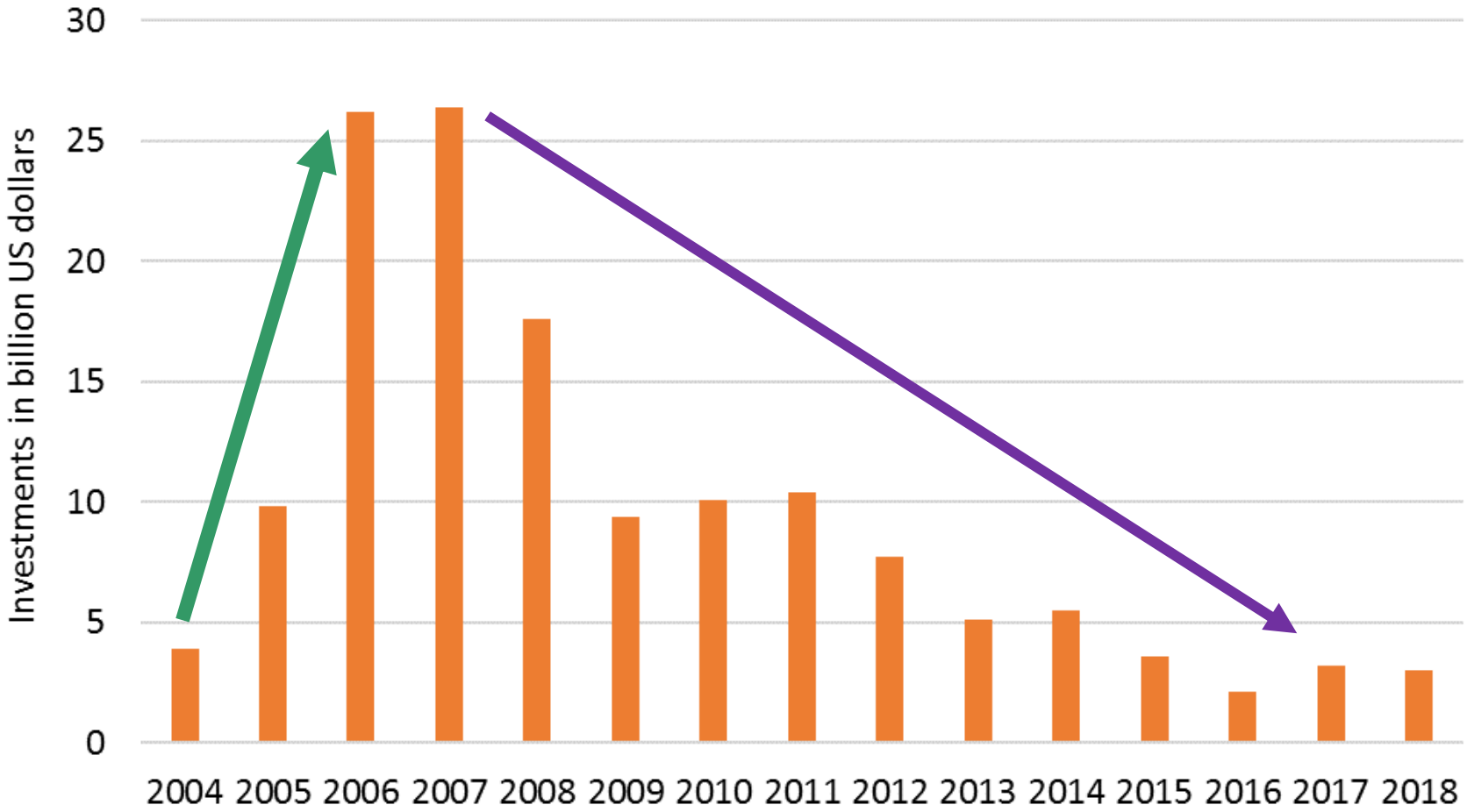
- Food and fuel competition

- Sustainability….risk of increase in GHG emissions – LUC

- Risks of degradation of land, forests, water resources and ecosystems - associated with use of freshwater, fertilizers and pesticides

- Economic viability…oil price (2. gen biofuels)

Global investment in biofuels



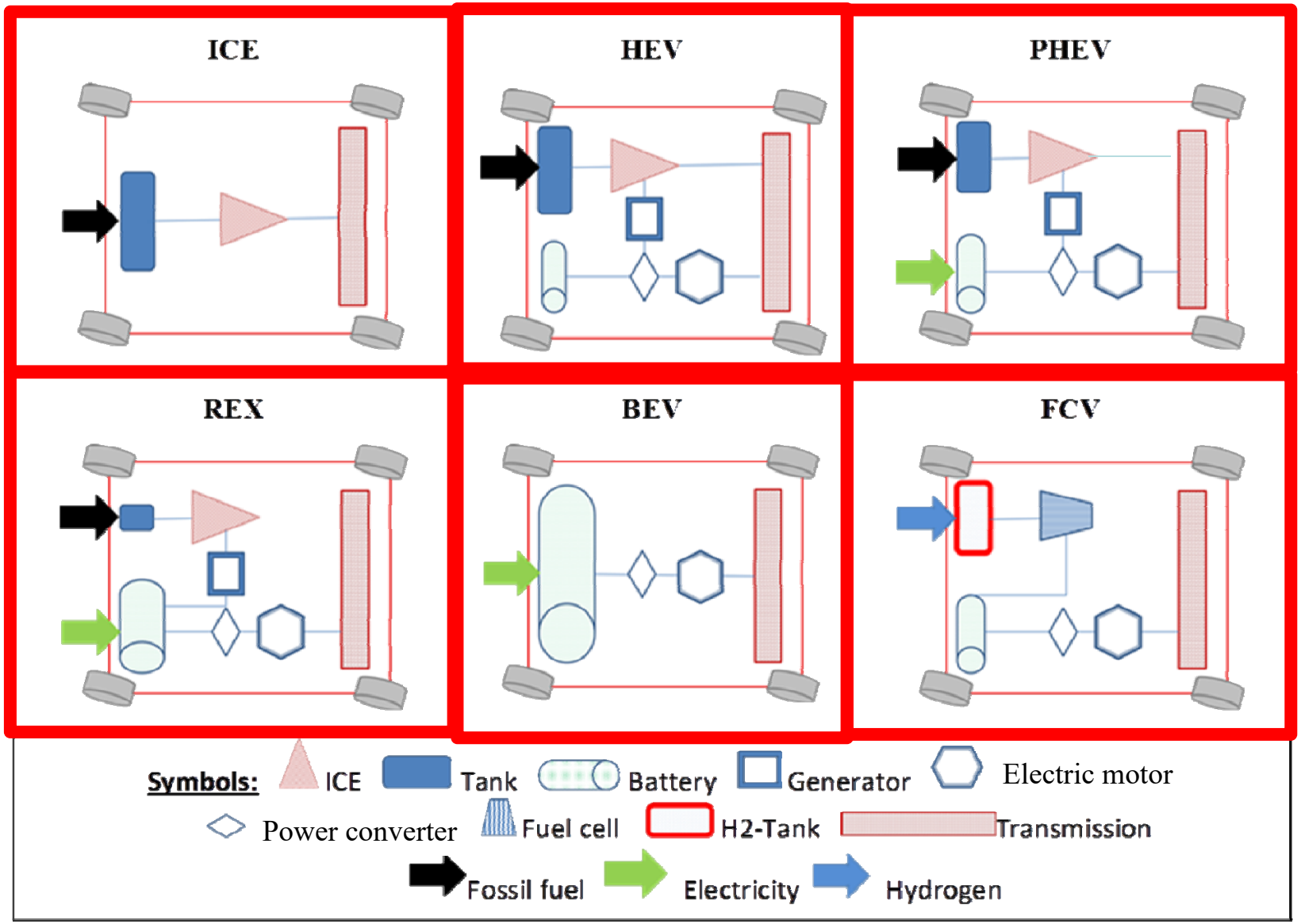
Future supply

- Optimistic estimates – biofuels contribute ca. one-third of global fuel supply in 2050
  - 2nd generation and 3rd generation –commercially available by 2030
- Oil price…lower oil prices…lower investment for biofuels
- Ban of conventional ICE vehicles…especially diesel

Alternatives

- Biofuels
- Electricity and electric vehicles
- Hydrogen and fuel cells

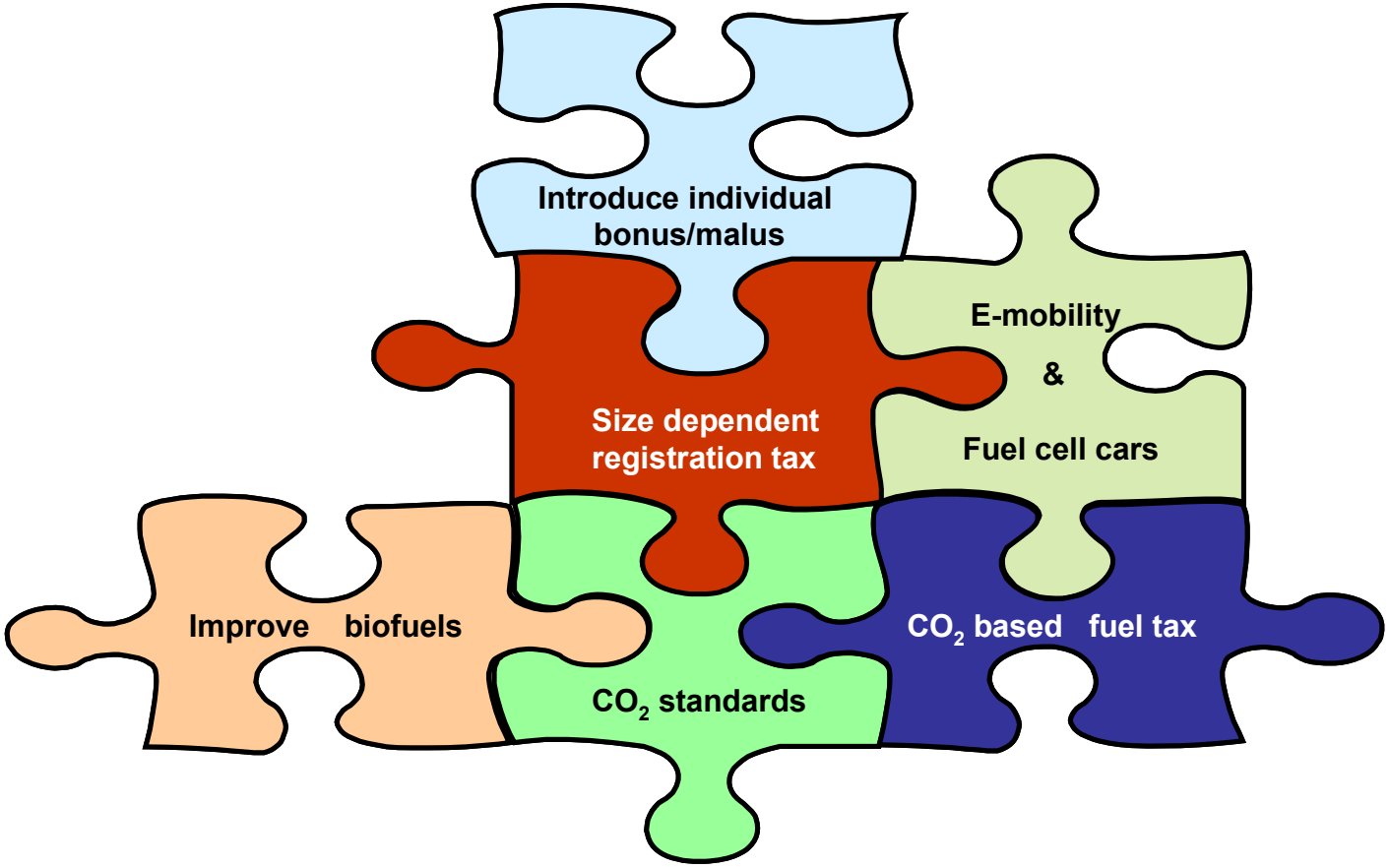
Electric vehicles



Electric vehicles

Advantages	Disadvantages
✓ Energy efficiency	– Costs
✓ Energy security	– Driving range
✓ Air pollution	– Charging time
✓ Noise reduction	– Charging infrastructure

Conclusions



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General conversion factors for energy

To: / From:	TJ	Gcal	Mtoe	MBtu	GWh
	multiply by:				
TJ	1	2.388×10^{2}	2.388×10^{-5}	9.478×10^{2}	2.778×10^{-1}
Gcal	4.187×10^{-3}	1	1.000×10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.187×10^{4}	1.000×10^{7}	1	3.968×10^{7}	1.163×10^{4}
MBtu	1.055×10^{-3}	2.520×10^{-1}	2.520×10^{-8}	1	2.931×10^{-4}
GWh	3.600	8.598×10^{2}	8.598×10^{-5}	3.412×10^{3}	1

Conversion factors for volume

From: \ To:	gal U.S.	gal U.K.	bbl	ft^3	l	m^3
	multiply by:					
U.S. gallon (gal)	1	8.327×10^{-1}	2.381×10^{-2}	1.337×10^{-1}	3.785	3.785×10^{-3}
U.K. gallon (gal)	1.201	1	2.859×10^{-2}	1.605×10^{-1}	4.546	4.546×10^{-3}
barrel (bbl)	4.200×10^{1}	3.497×10^{1}	1	5.615	1.590×10^{2}	1.590×10^{-1}
cubic foot (ft^3)	7.481	6.229	1.781×10^{-1}	1	2.832×10^{1}	2.832×10^{-2}
litre (l)	2.642×10^{-1}	2.200×10^{-1}	6.290×10^{-3}	3.531×10^{-2}	1	1.000×10^{-3}
cubic metre (m^3)	2.642×10^{2}	2.200×10^{2}	6.290	3.531×10^{1}	1.000×10^{3}	1

Unit abbreviations

bcm	billion cubic metres	**MBtu**	million British thermal units
Gcal	gigacalorie	**Mt**	million tonnes
GCV	gross calorific value	**Mtoe**	million tonnes of oil equivalent
GW	gigawatt	**MWh**	megawatt hour
GWh	gigawatt hour	**PPP**	purchasing power parity
kb/cd	thousand barrels per calendar day	**t**	metric ton = tonne = 1 000 kg
kcal	kilocalorie	**TJ**	terajoule
kg	kilogramme	**toe**	tonne of oil equivalent = 10^7 kcal
kJ	kilojoule	**TWh**	terawatt hour
kWh	kilowatt hour	**USD**	United States dollar

OECD countries

- Australia,
- Austria,
- Belgium,
- Canada,
- Chile,
- Czech Republic,
- Denmark,
- Estonia,
- Finland,
- France,
- Germany,
- Greece,
- Hungary,
- Iceland,
- Ireland,
- Israel,
- Italy,
- Japan,
- Korea,
- Luxembourg,
- Mexico,
- Netherlands,
- New Zealand,
- Norway,
- Poland,
- Portugal,
- Slovak Republic,
- Slovenia,
- Spain,
- Sweden,
- Switzerland,
- Turkey,
- United Kingdom,
- United States.

EU-28 countries

- Austria
- Belgium
- Bulgaria
- Croatia
- Cyprus
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- Ireland
- Italy
- Latvia
- Lithuania
- Luxembourg
- Malta
- Netherlands
- Poland
- Portugal
- Romania
- Slovakia
- Slovenia
- Spain
- Sweden
- United Kingdom

Abbreviations

- AEC – Alternative energy carrier
- BAU - Business-as-usual scenario
- CNG - Compressed natural gas
- FT-Diesel - Fischer-Tropsch diesel
- ILUC - Indirect Land Use Change
- LNG - Liquefied Natural Gas
- PCE - Personal Consumption Expenditures
- RME - Rape Methyl Ester
- SNG – Synthetic Natural Gas
- SUV - A sport utility vehicle or suburban utility vehicle (SUV) is a vehicle classified as a light truck