Energy and CO$_2$ Emissions in Transport

Amela Ajanovic
Energy Economics Group (EEG)
Institute of Energy Systems and Electrical Drives
Vienna University of Technology
Tel.   +43-1-58801-370364
Web: http://eeg.tuwien.ac.at

Contents

1. Introduction
2. Historical developments
3. Indicators of recent development
4. Technical, economic and ecological aspects
5. Energy policies
6. Future scenarios and perspectives

Basic principle:

$$S = f(E, \eta(T_c), \eta(T_{is}))$$
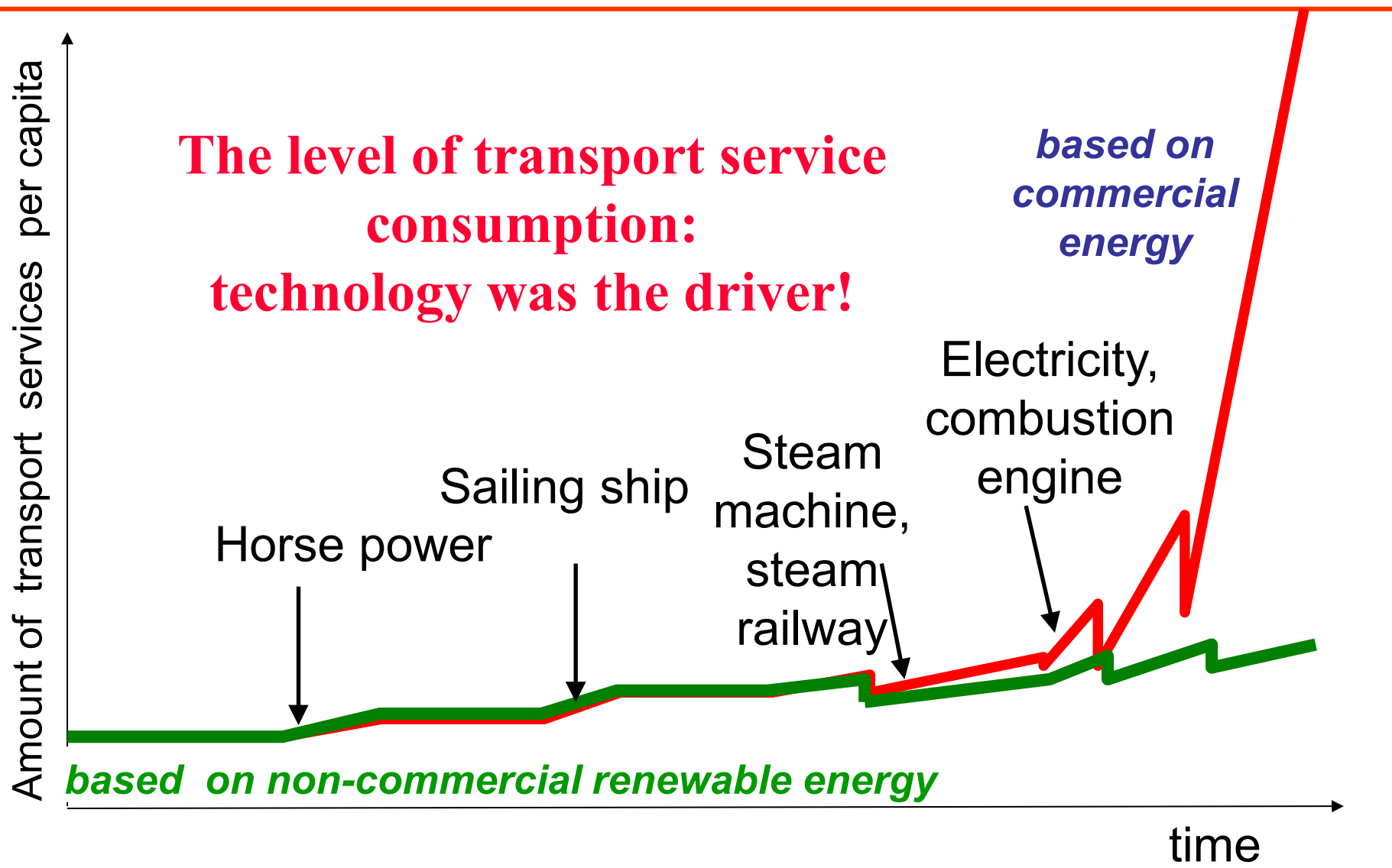
Infrastructur

**Service:
km driven**

Fuel mix

**Efficiency:
Liter/100 km**

2. Historical developments

The level of transport service consumption: technology was the driver!

Amount of transport services per capita

based on commercial energy

based on non-commercial renewable energy

Horse power

Sailing ship

Steam machine, steam railway
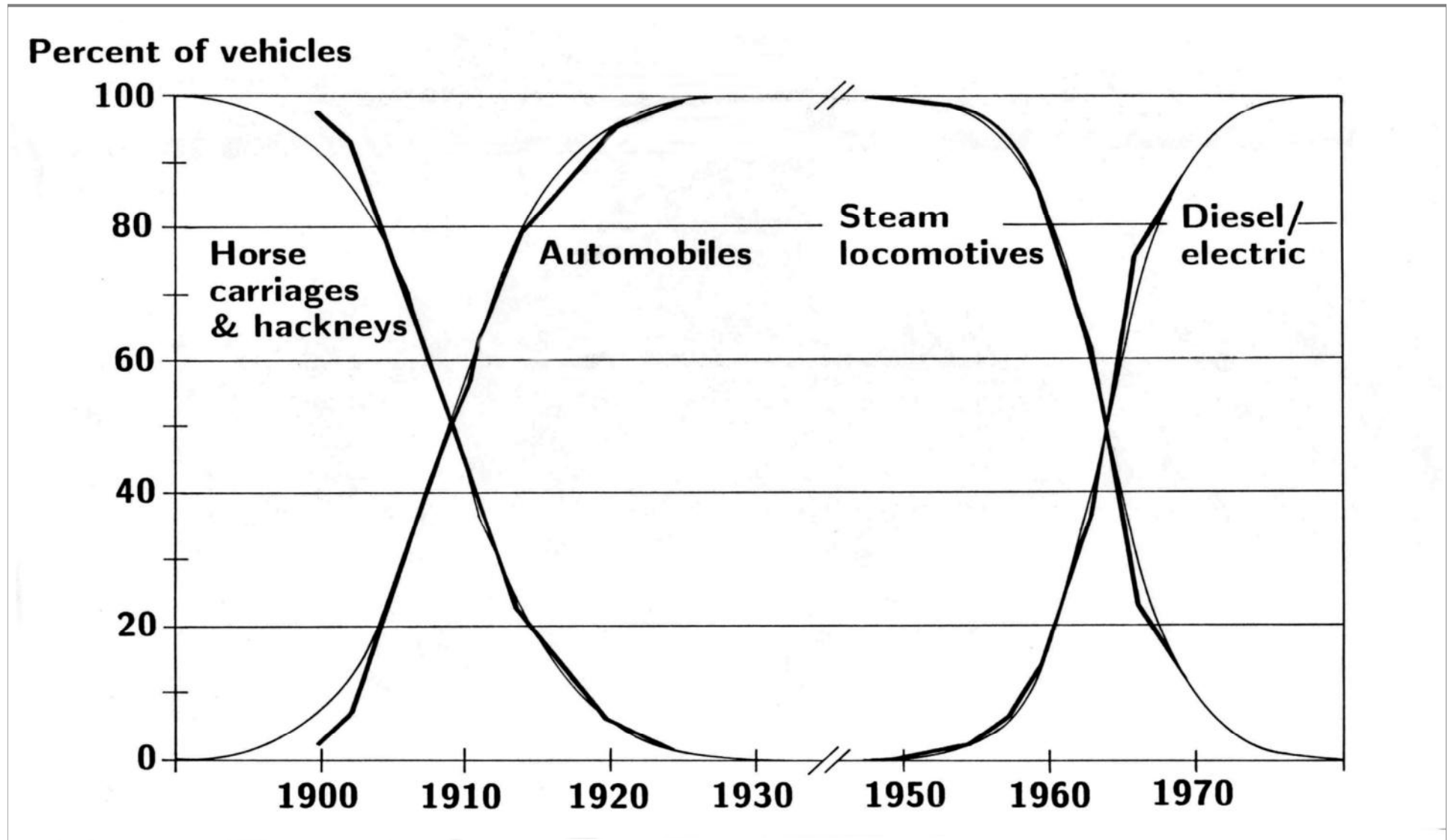
Electricity, combustion engine

time

USA – Number of Horses and Cars
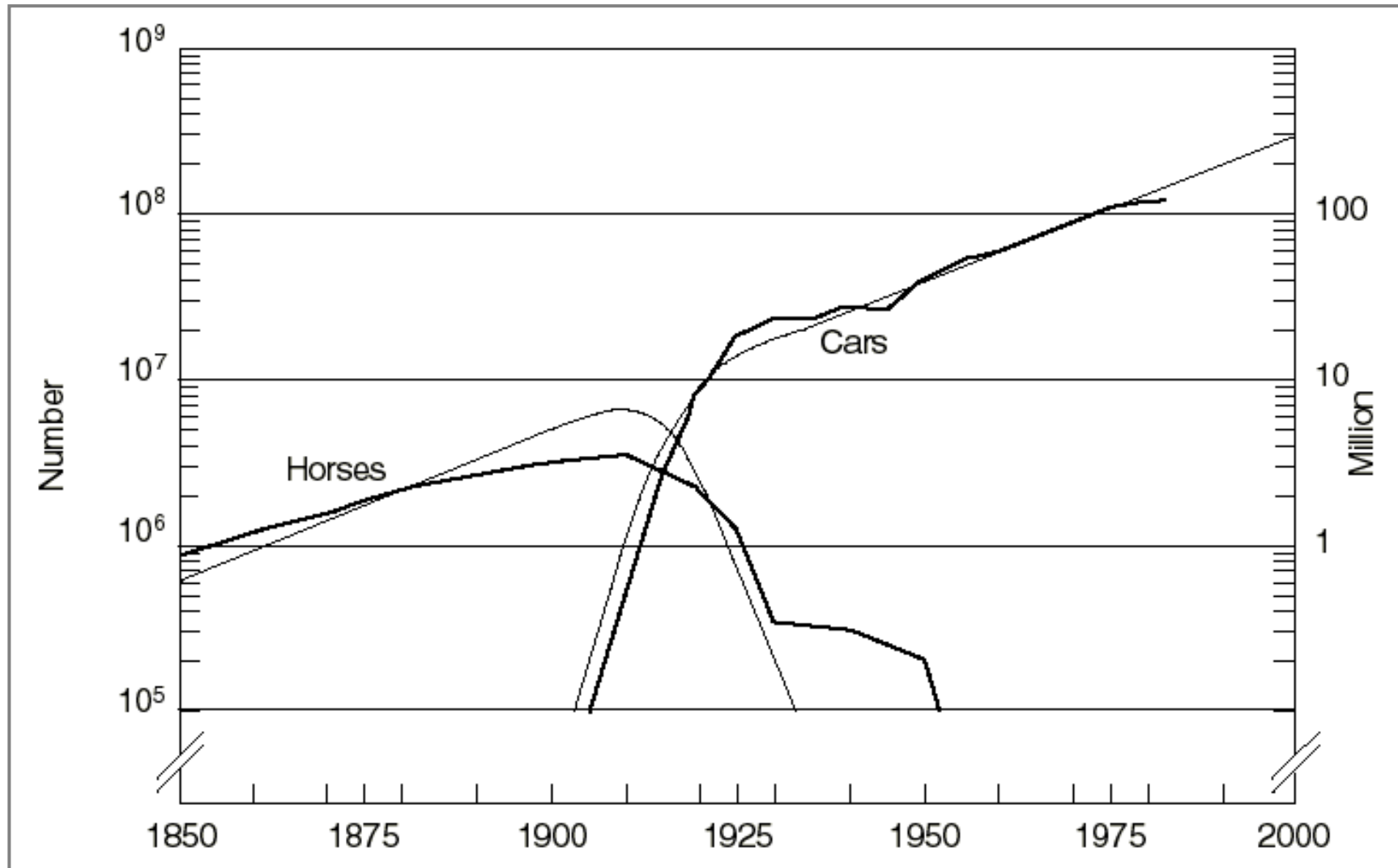
Source: Nakicenovic, 1984.

UK – Replacement within Vehicle Fleets
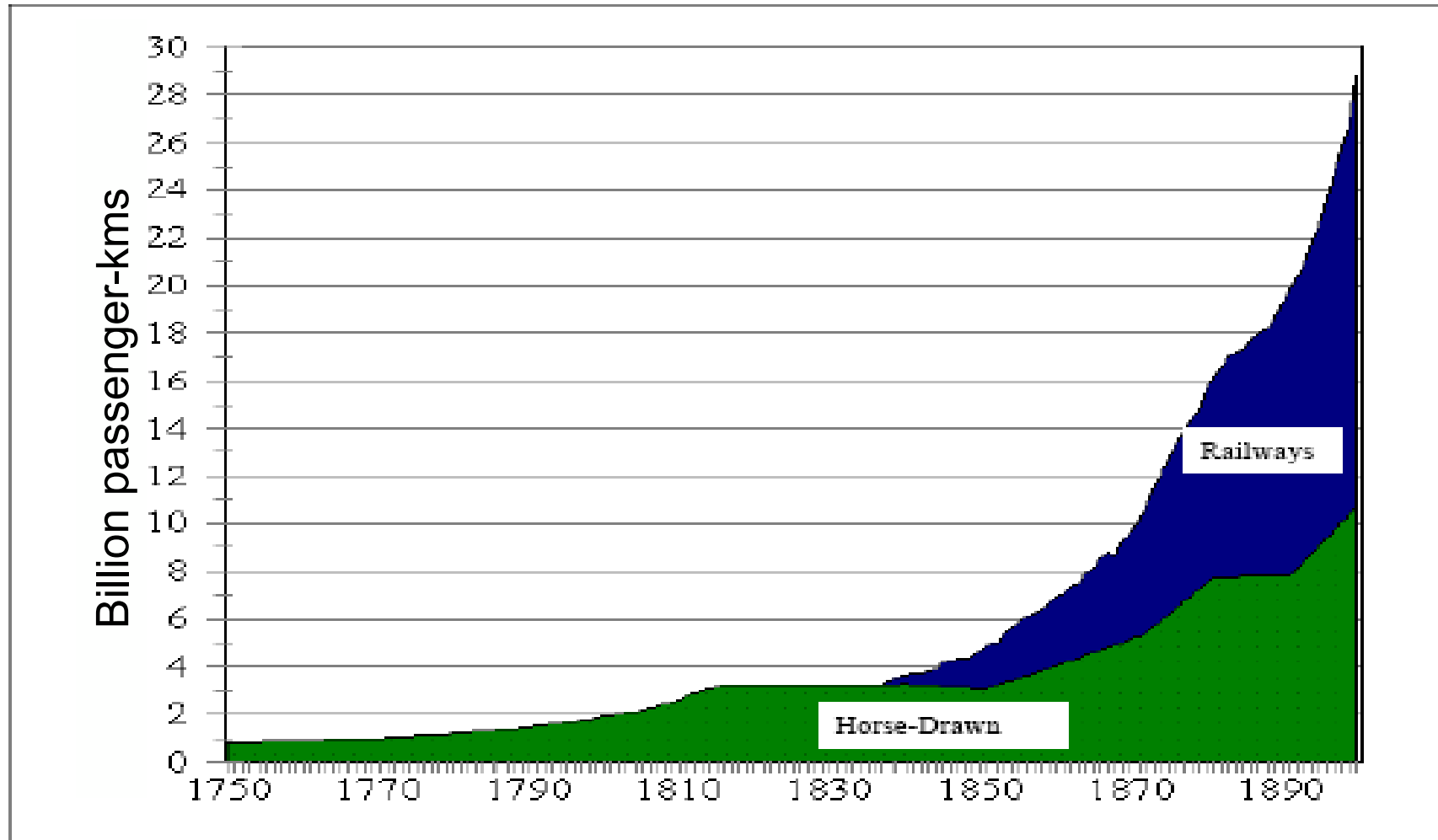
The Speed of Transport (Kilometres per Hour)

London – Chester (290 km)
- 1657 – 6 days
- 1704 – 4 days
- 1837 – 22 hours

Railways

Stage-Coach

Carriage

Source: Fouquet,2003
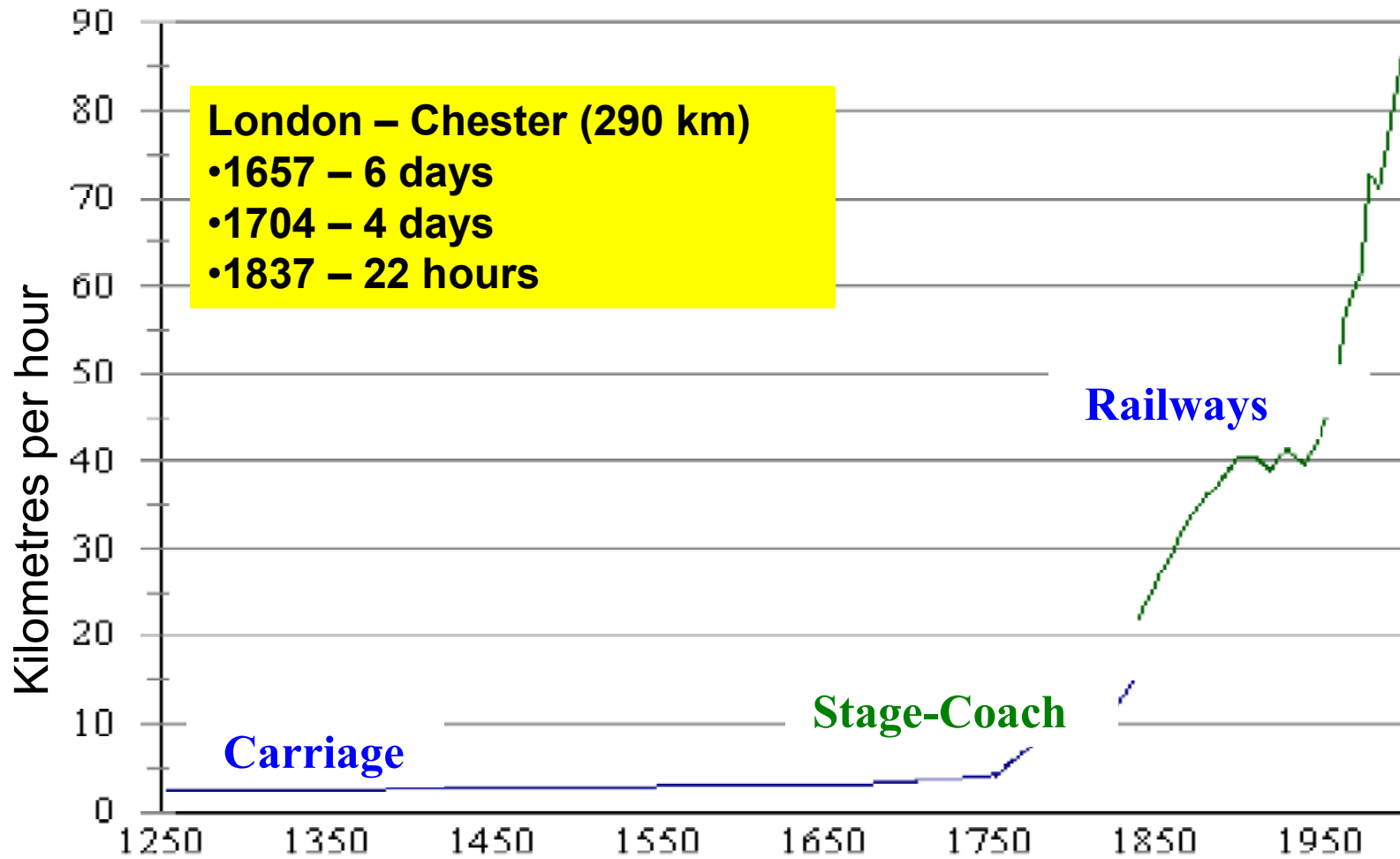
Price of Passenger
Transport (per passenger-kilometer-hour)

The price of service dropped dramatically!
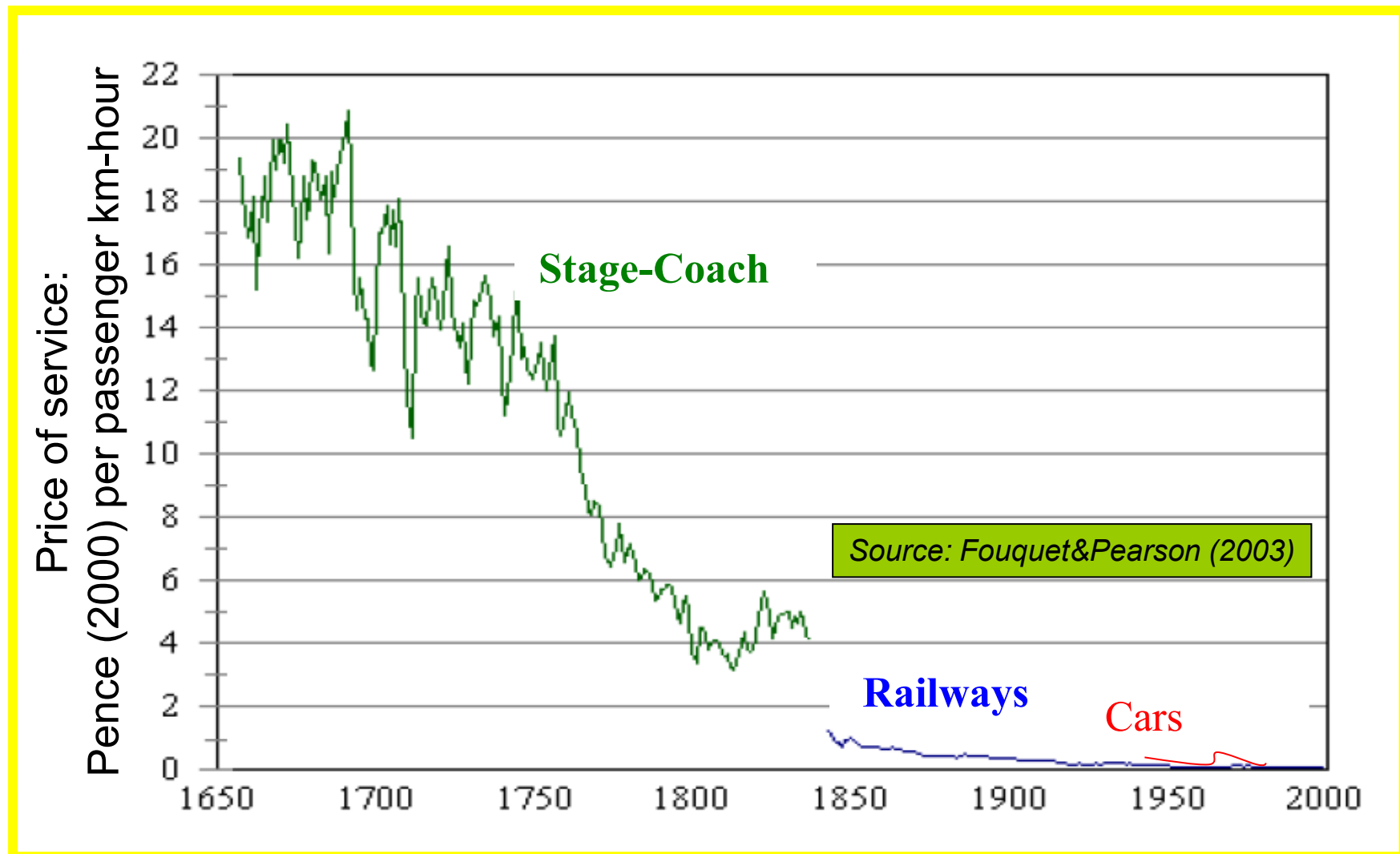
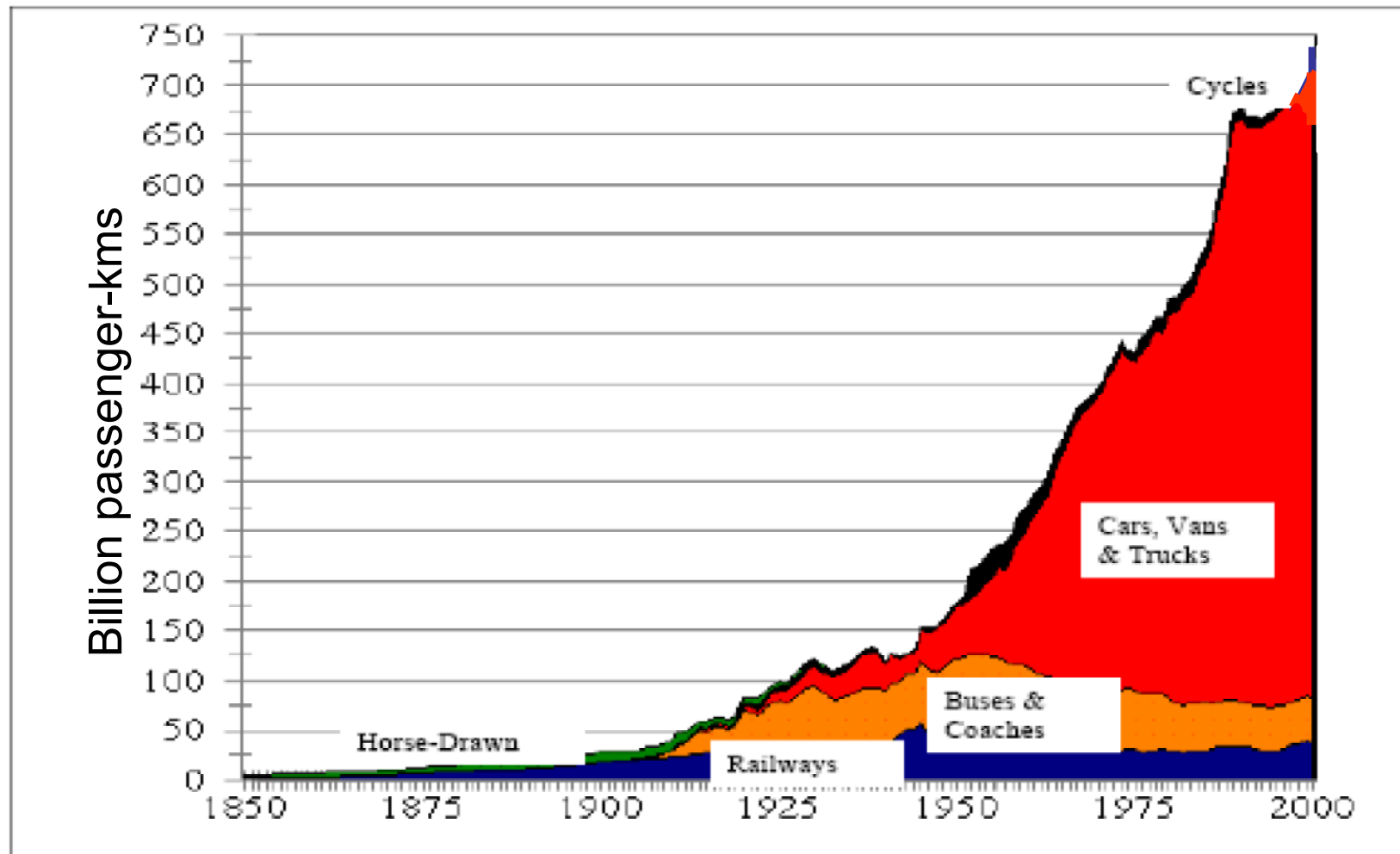# UK: The Use of Passenger Transport (per Passenger-Kilometre), 1750-1900

The demand for service

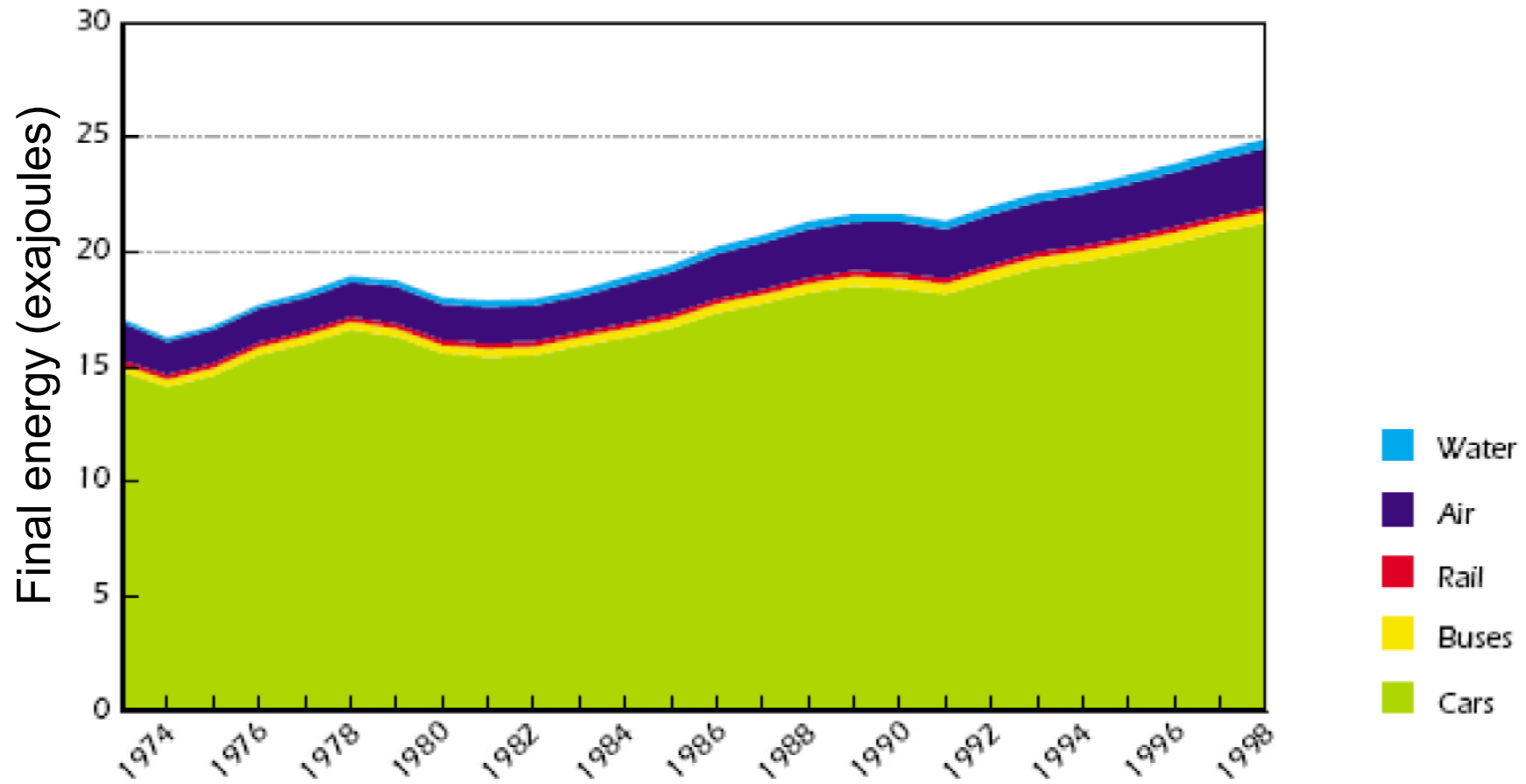# UK: The Use of Passenger Transport (per Passenger-Kilometre), 1850-2000

Source: Fouquet,2003

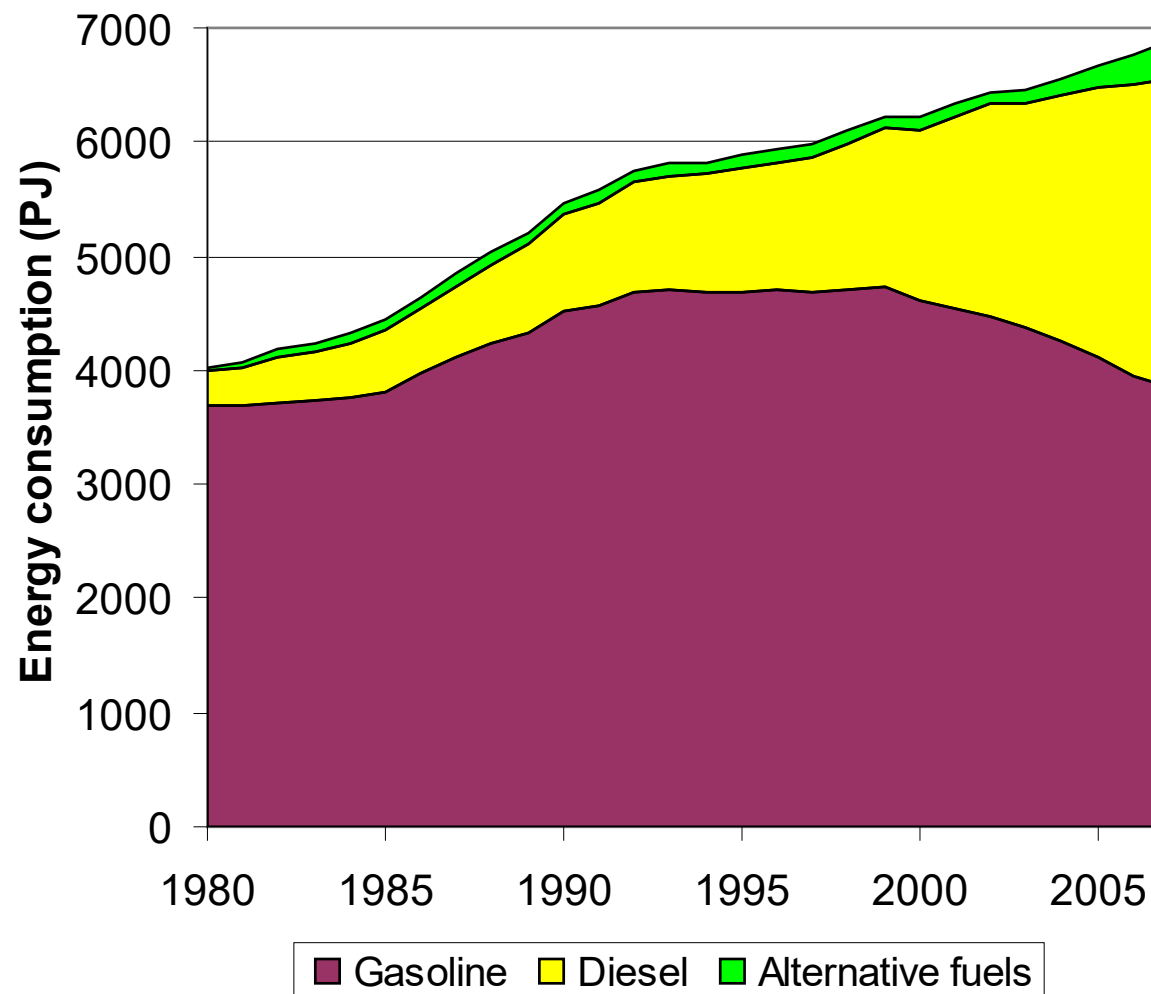# 3. Indicators of recent developments, current situation

Energy Use in Passenger Transport by Mode

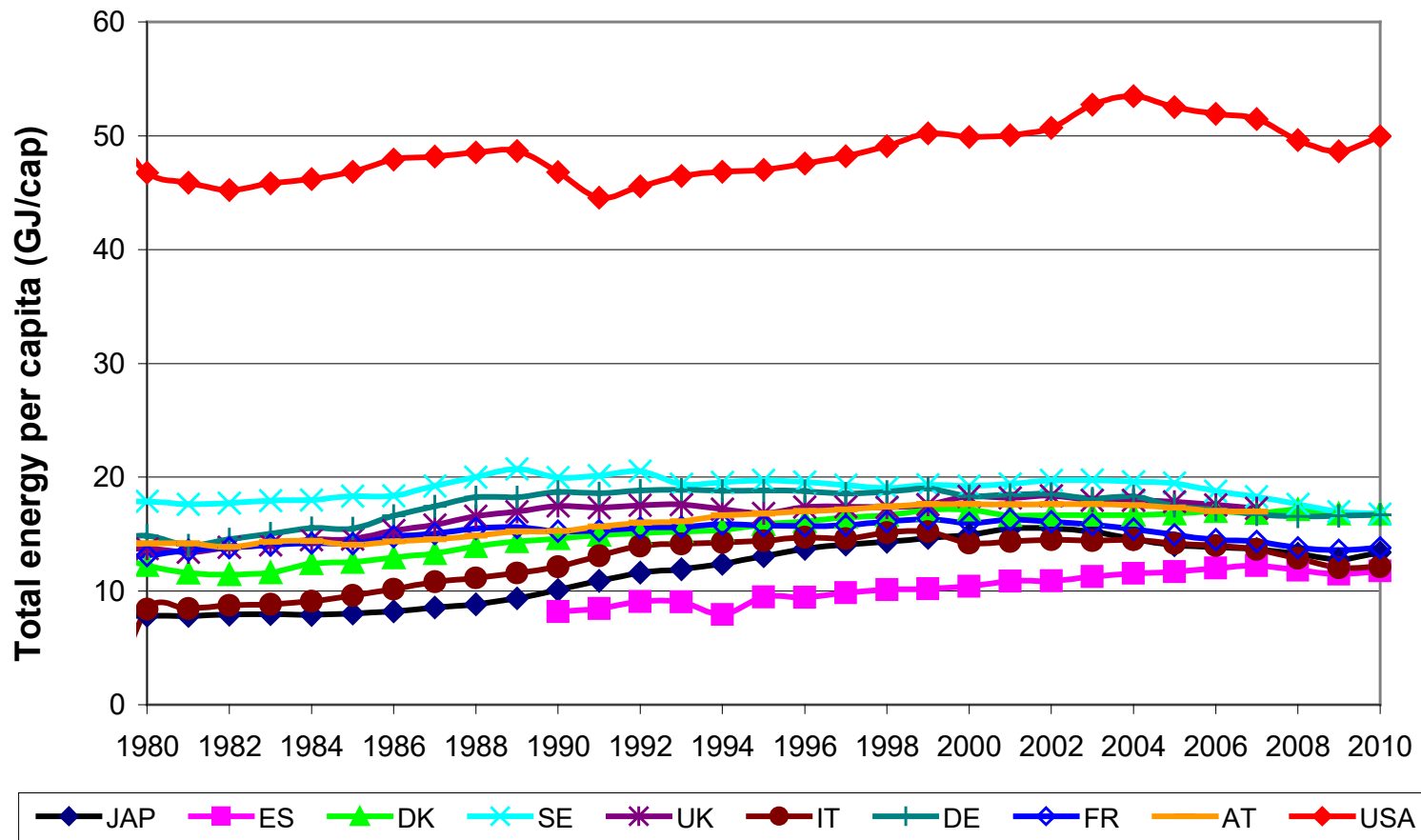**Energy used to move people was 45% higher in 1998 than in 1973**

Source: IEA, 2004

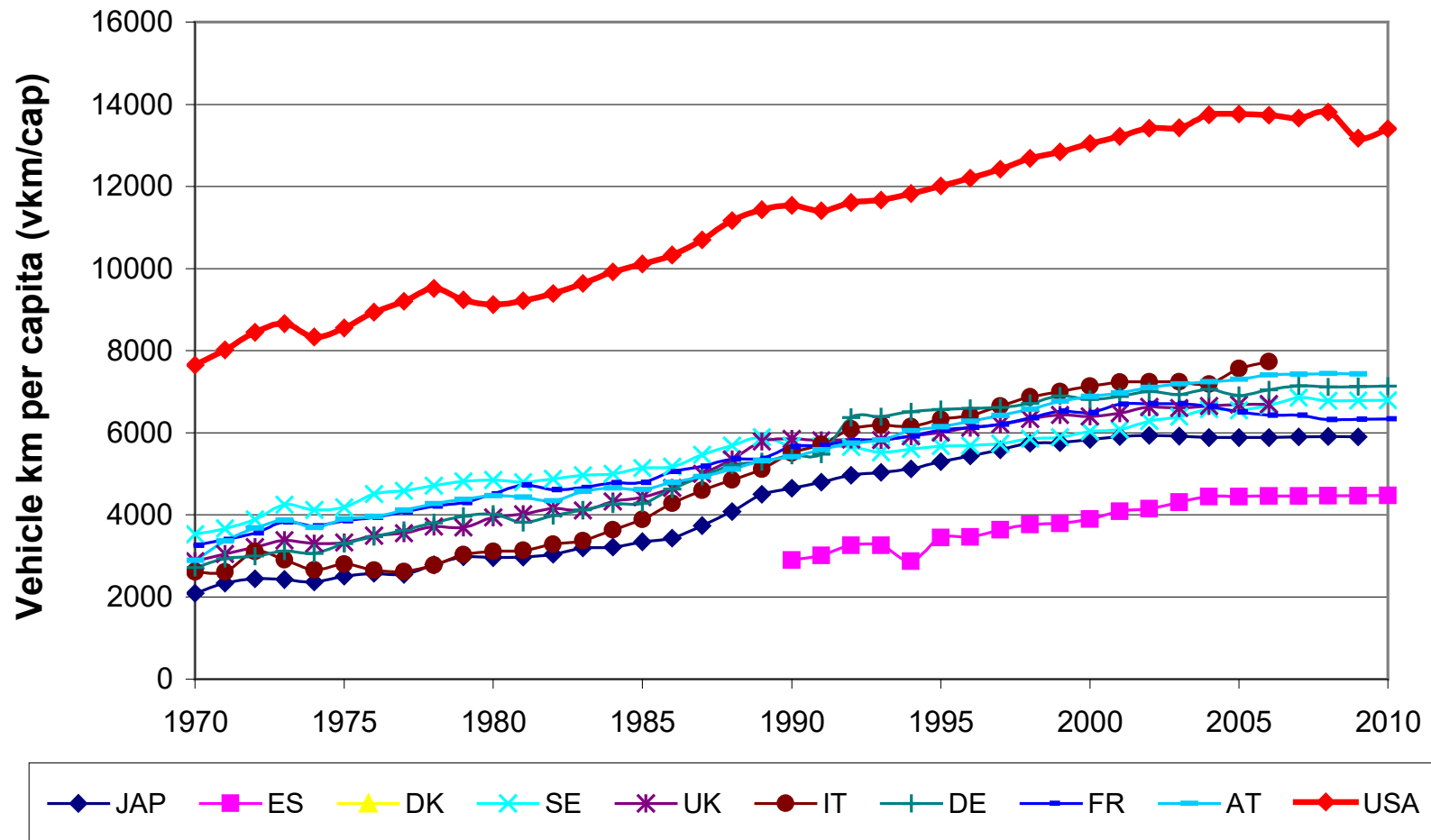# Energy consumption in car passenger transport in EU-15 by fuel, 1980 – 2007
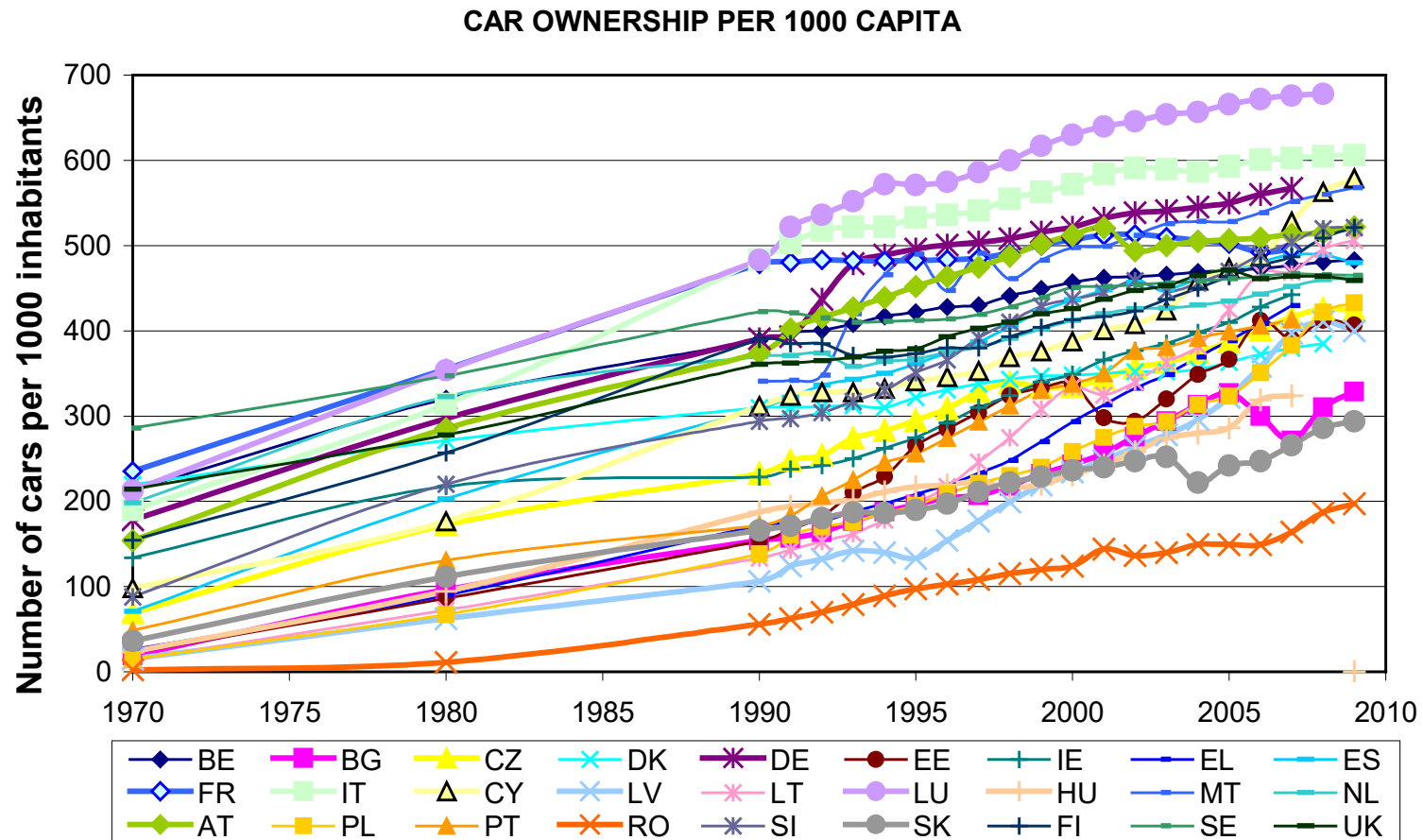
Energy consumption

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

Travel activity

Development of vehicle kilometer per capita

Development of car stock

CAR OWNERSHIP PER 1000 CAPITA

Car ownership per 1000 capita in EU-27 countries 1970 – 2009

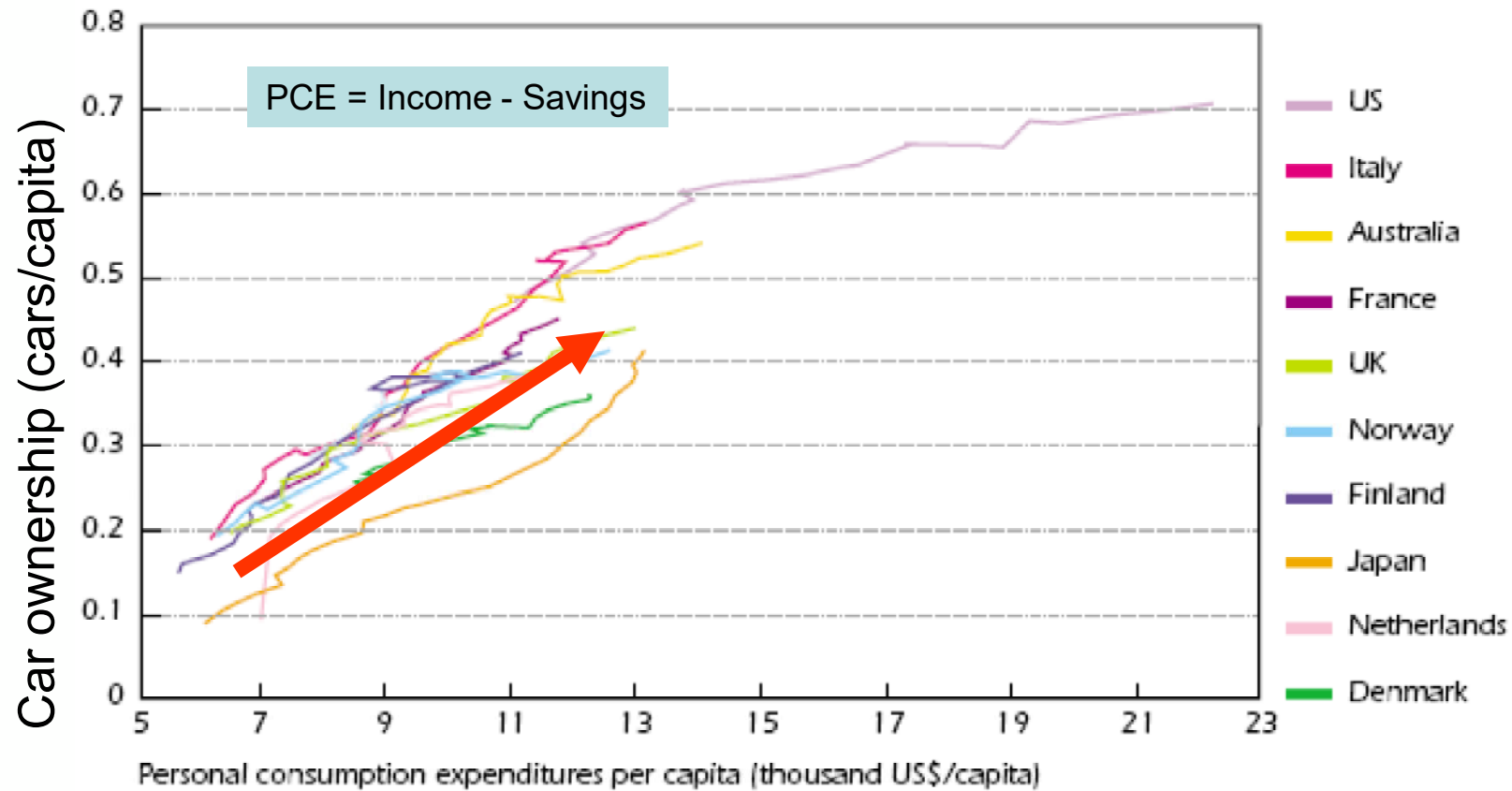# Increases in power of cars
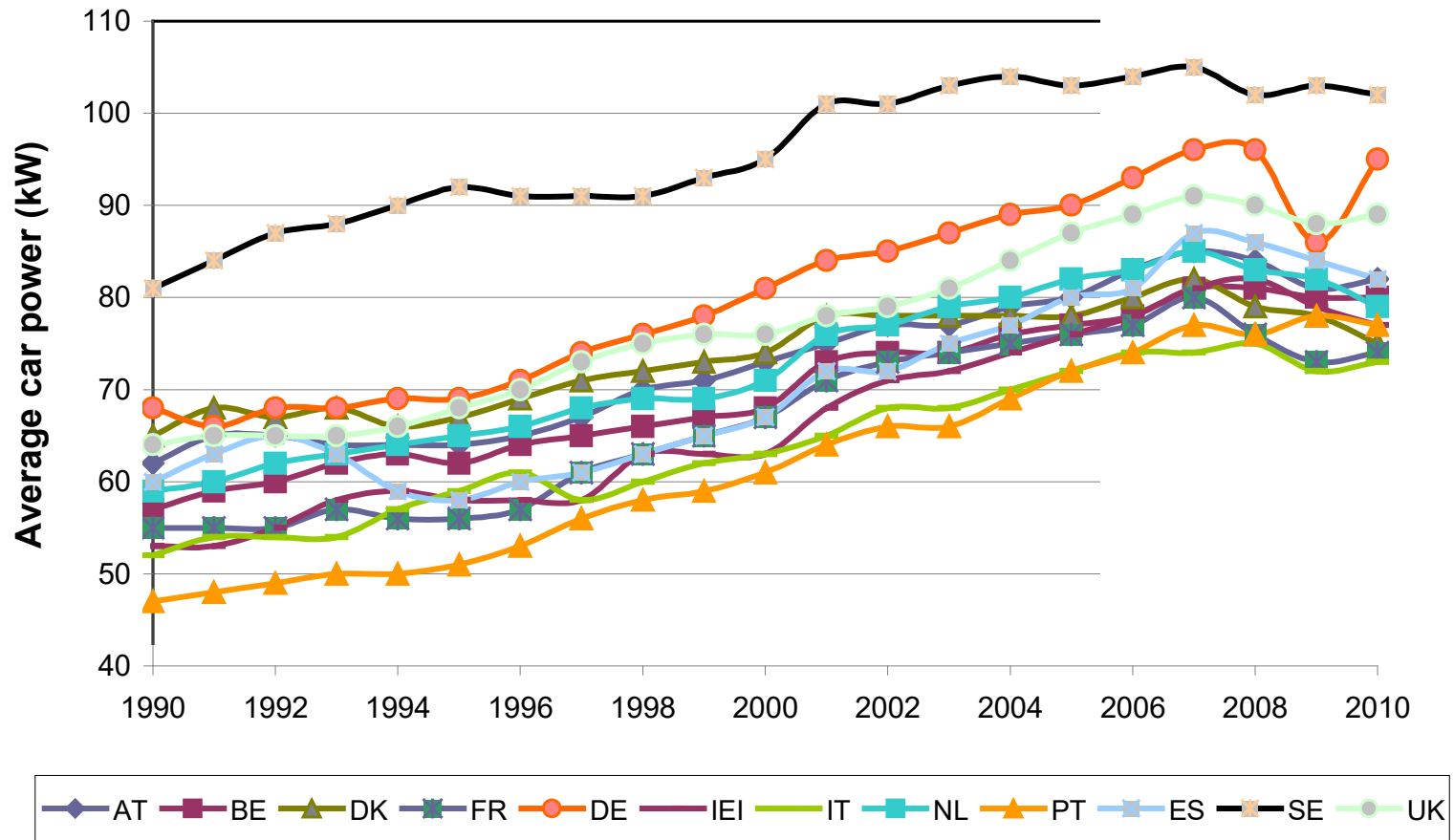
Average developments of car power (kW) of new cars in various EU-15 countries from 1990 to 2010

Car Ownership and Income

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

PCE = Income - Savings

Car ownership (cars/capita)

Personal consumption expenditures per capita (thousand US$/capita)

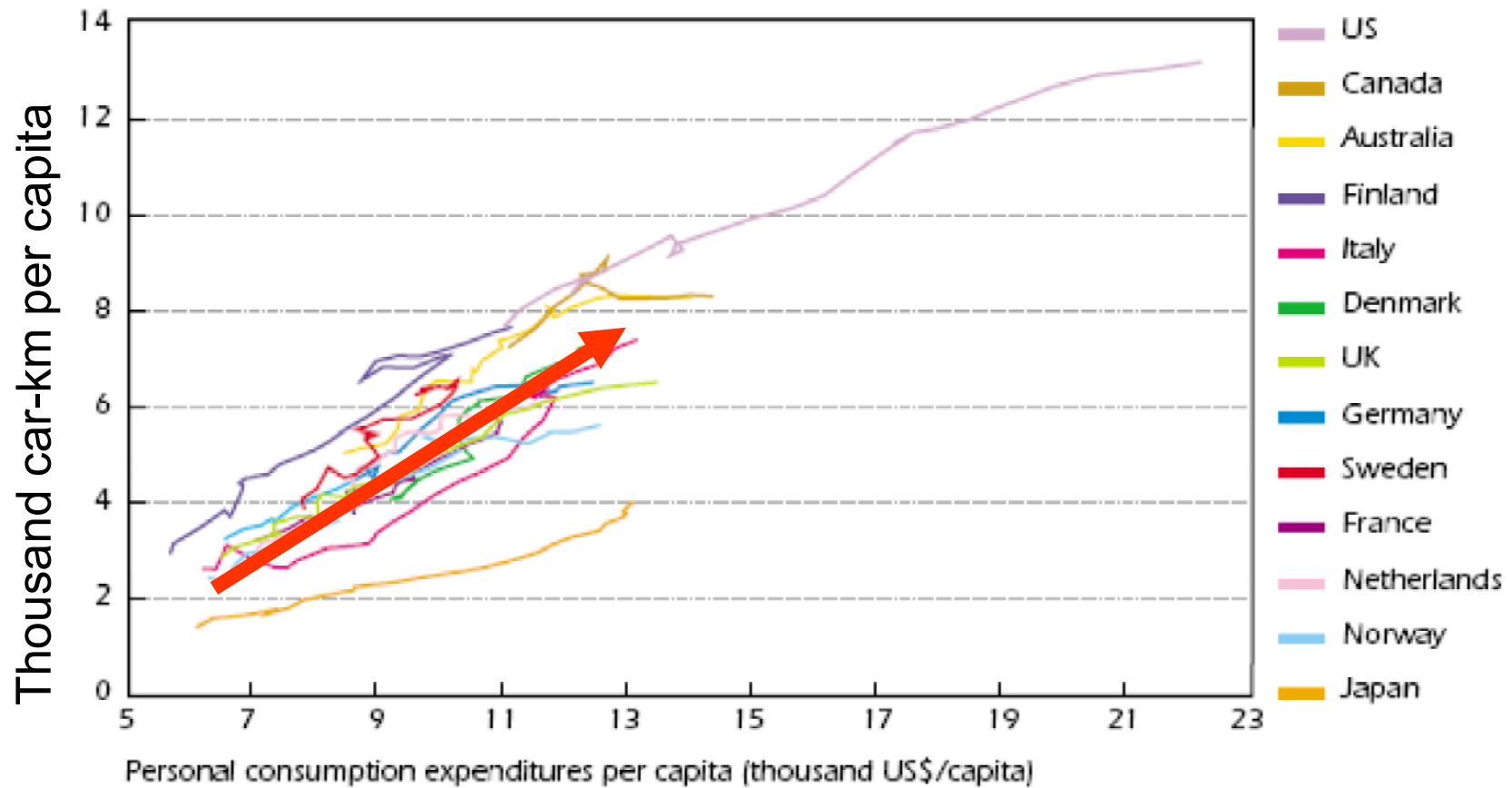Legend: US, Italy, Australia, France, UK, Norway, Finland, Japan, Netherlands, Denmark
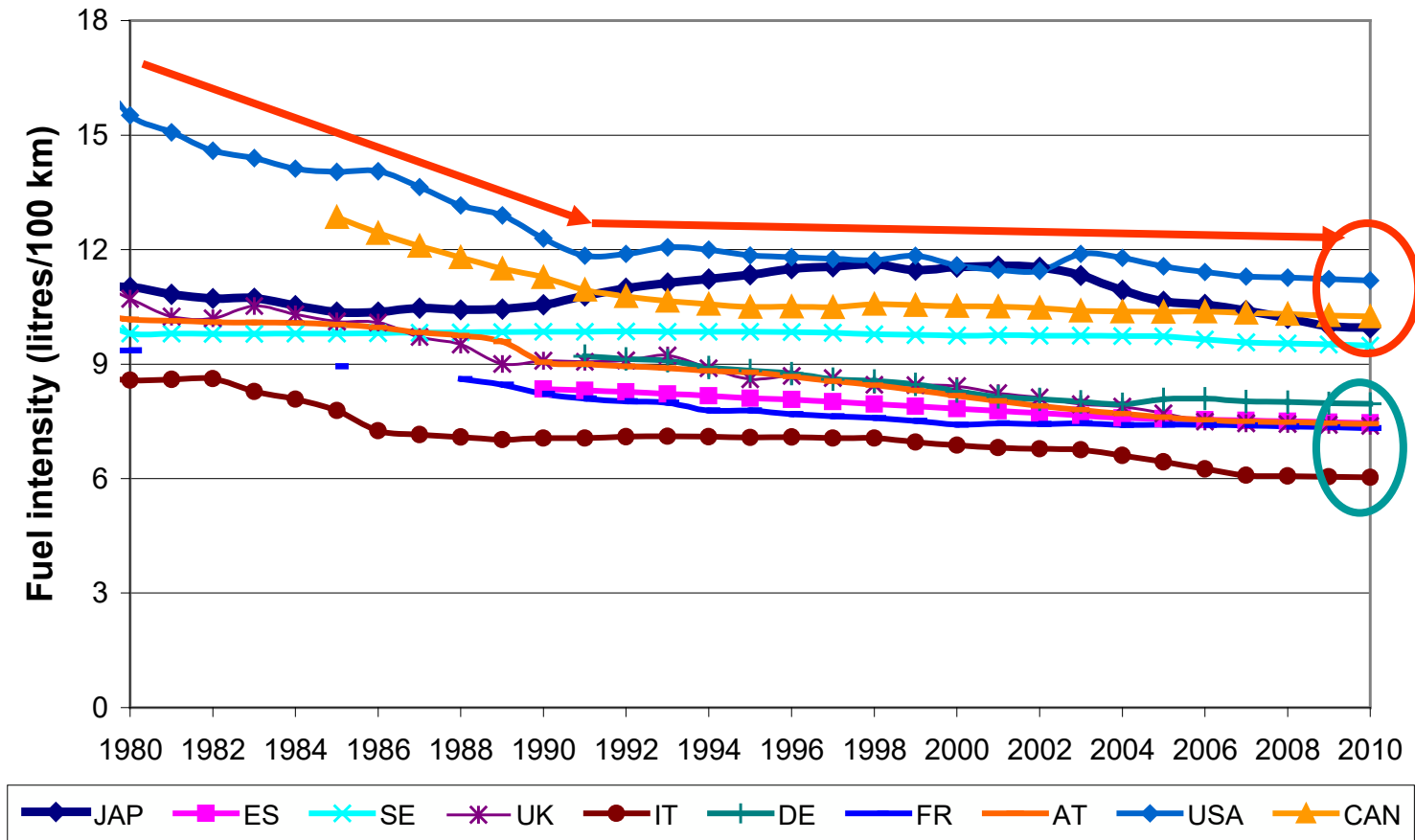
Source: IEA, 2004

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 (Diesel and LPG are converted to liters of gasoline at their energy content.
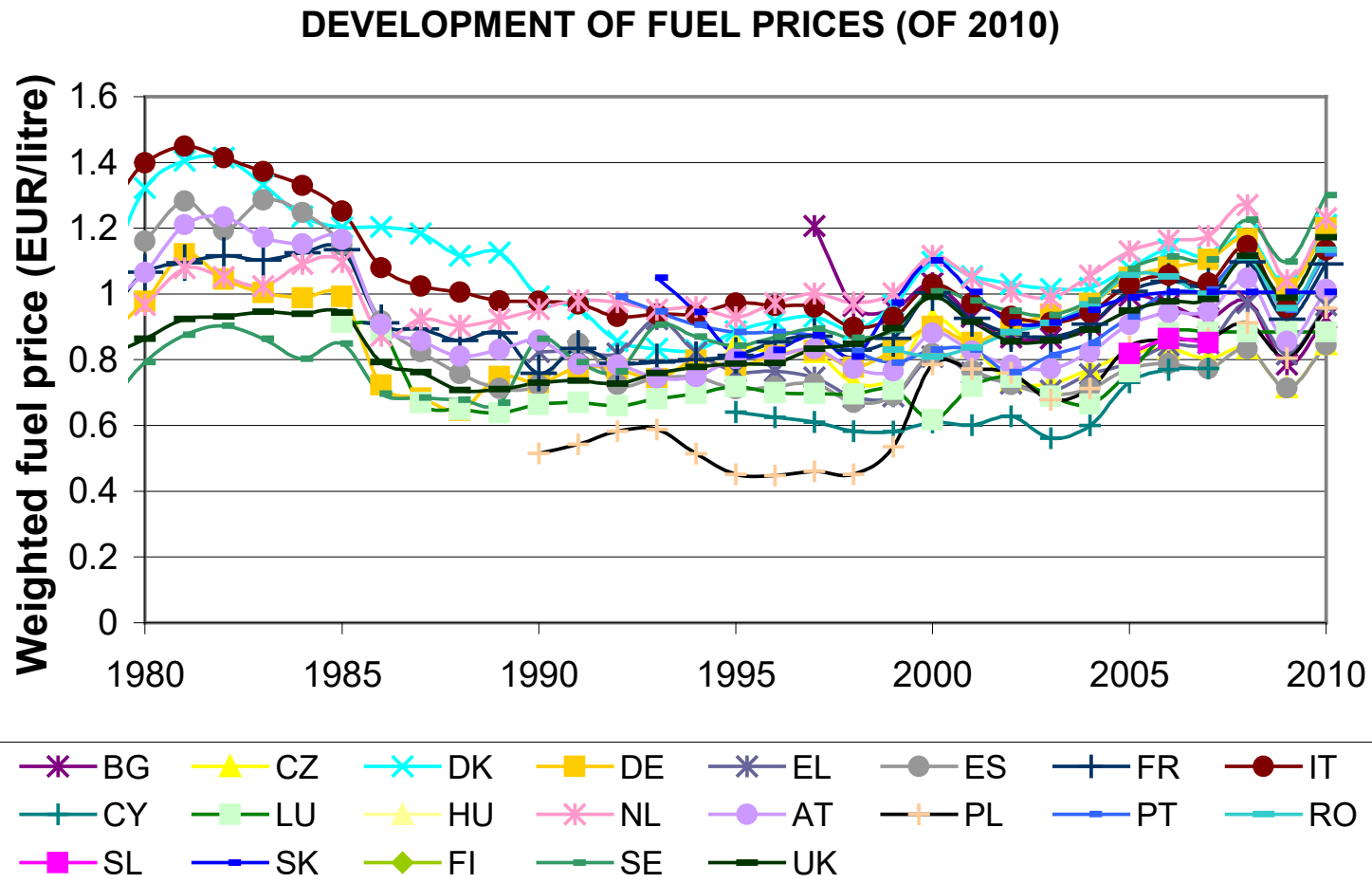1 litre diesel = 1.12 litre gasoline)

Gasoline Prices

Trends in Retail Gasoline Prices in Real Terms, Including Taxes

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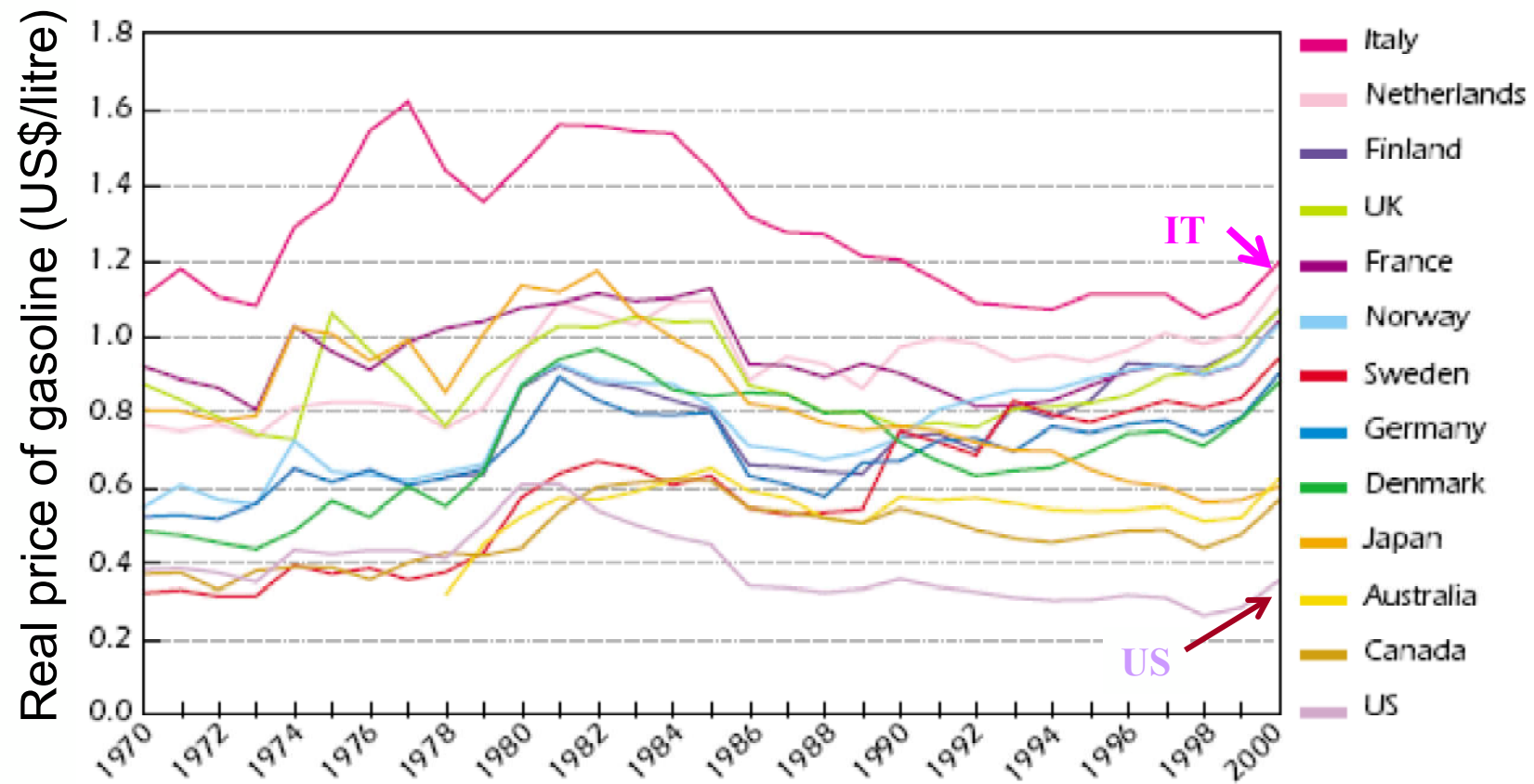
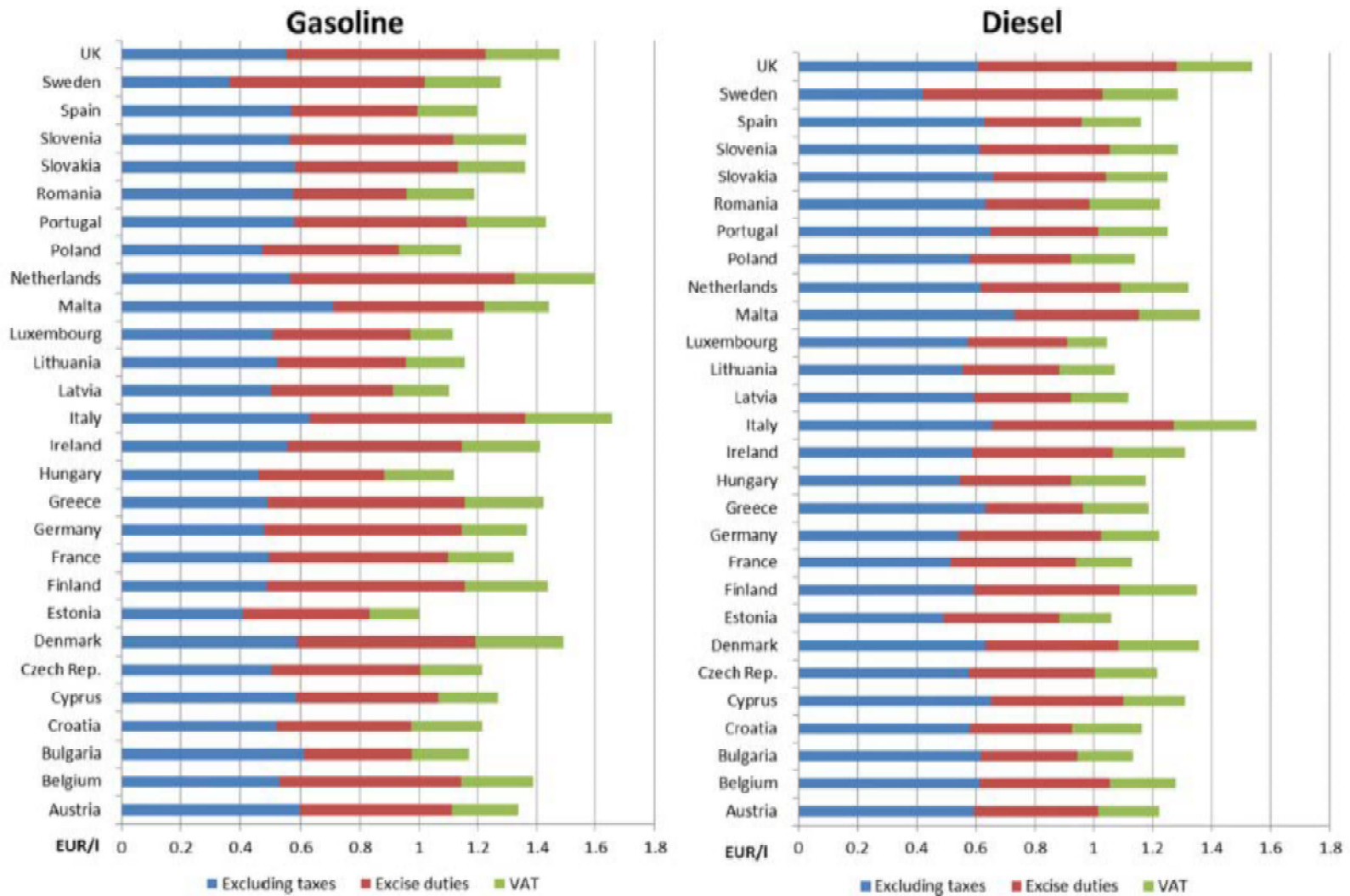

Source: IEA, 2004

Development of fuel prices

DEVELOPMENT OF FUEL PRICES (OF 2010)

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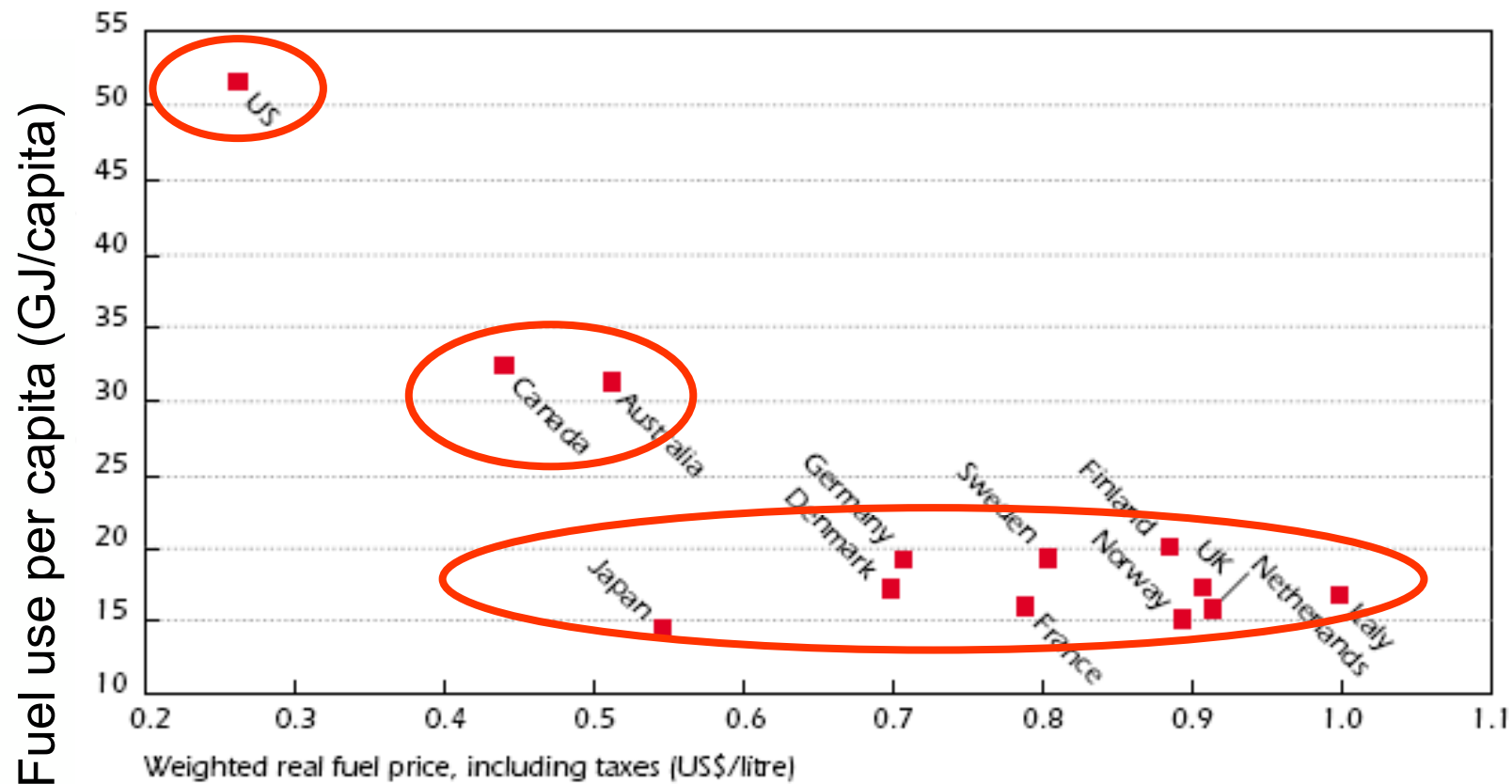
Price structure of gasoline and diesel

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 vs. 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
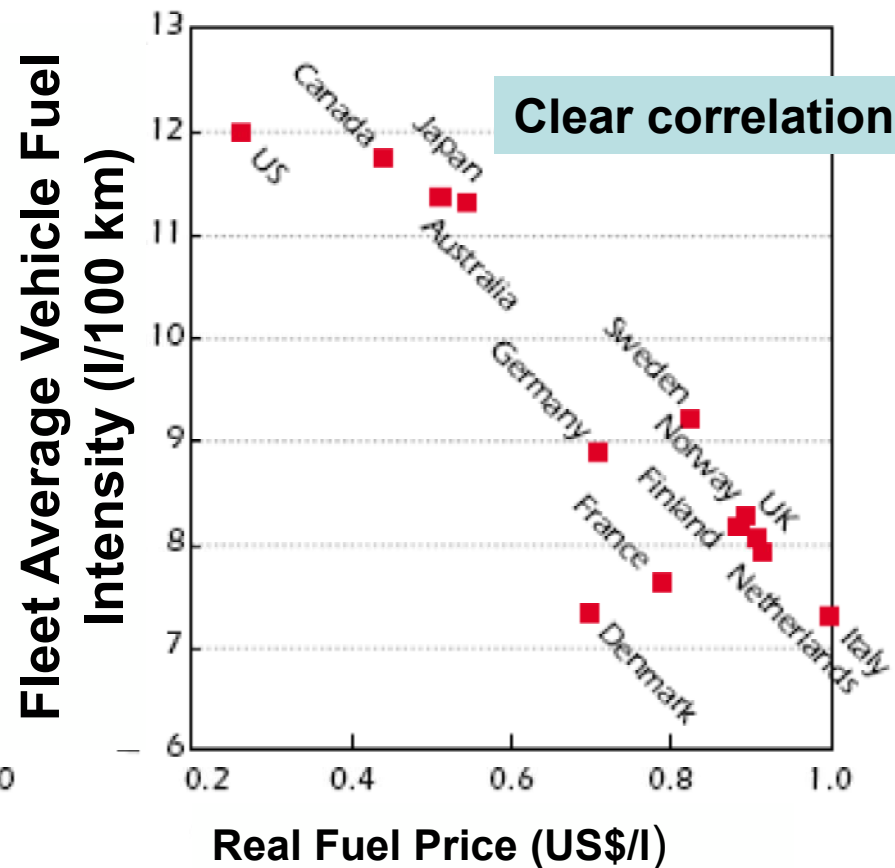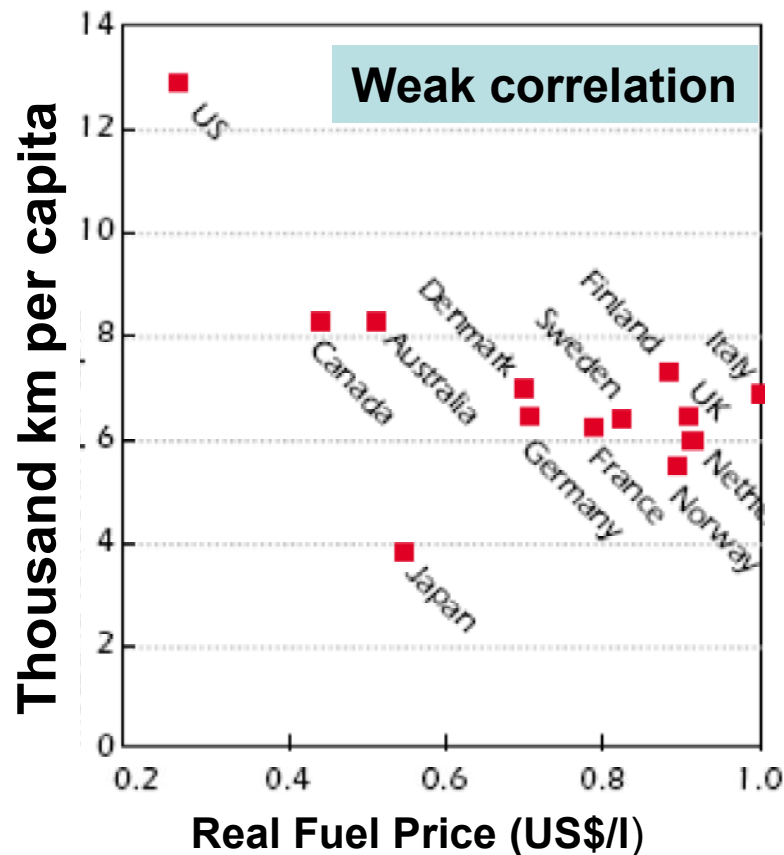
- Passenger transport is almost exclusively based on petroleum products. Growth in passenger travel has been the biggest contributor to increased oil demand.

- 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.

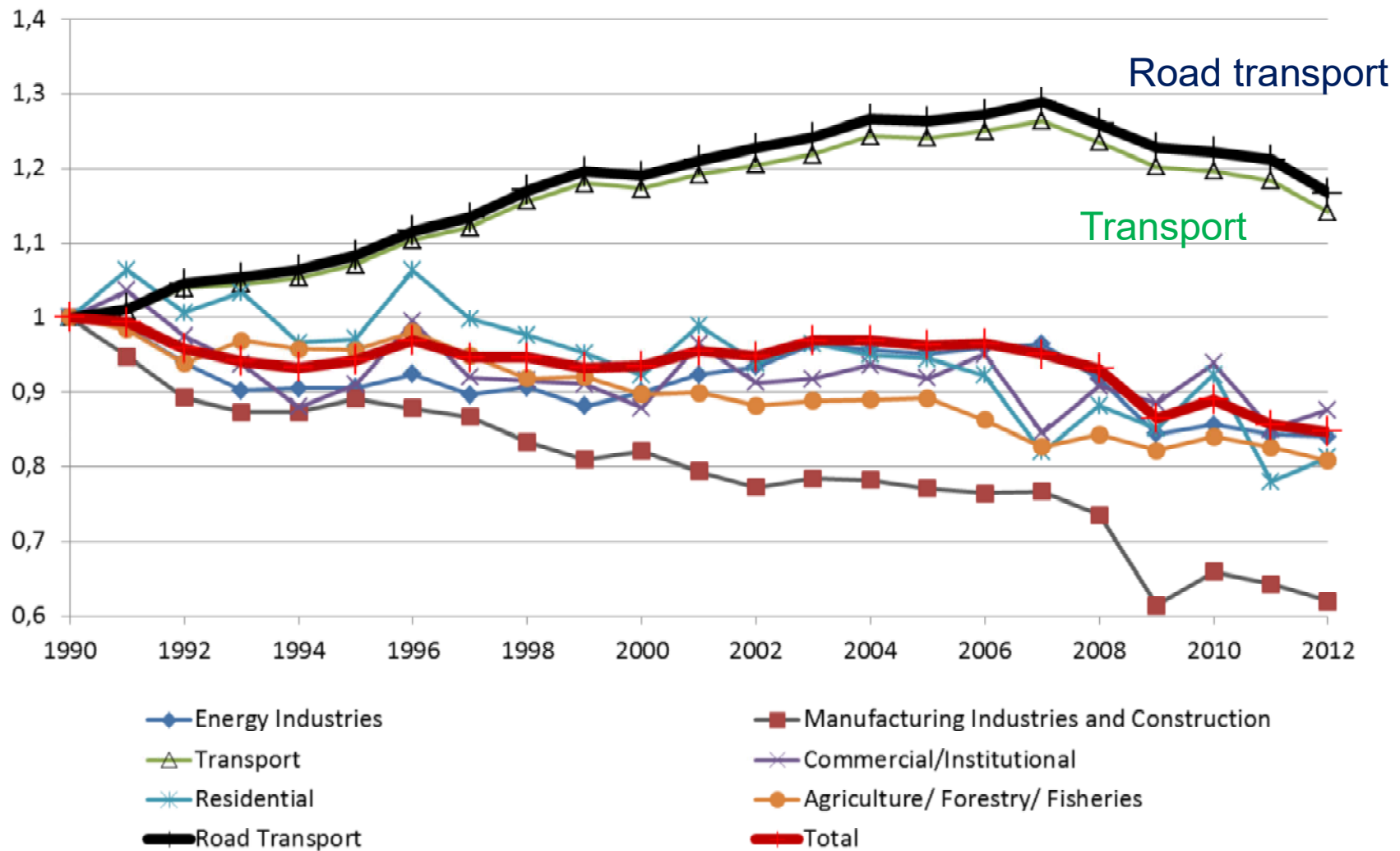# 4. Comparison of technical, economic, and ecological aspects
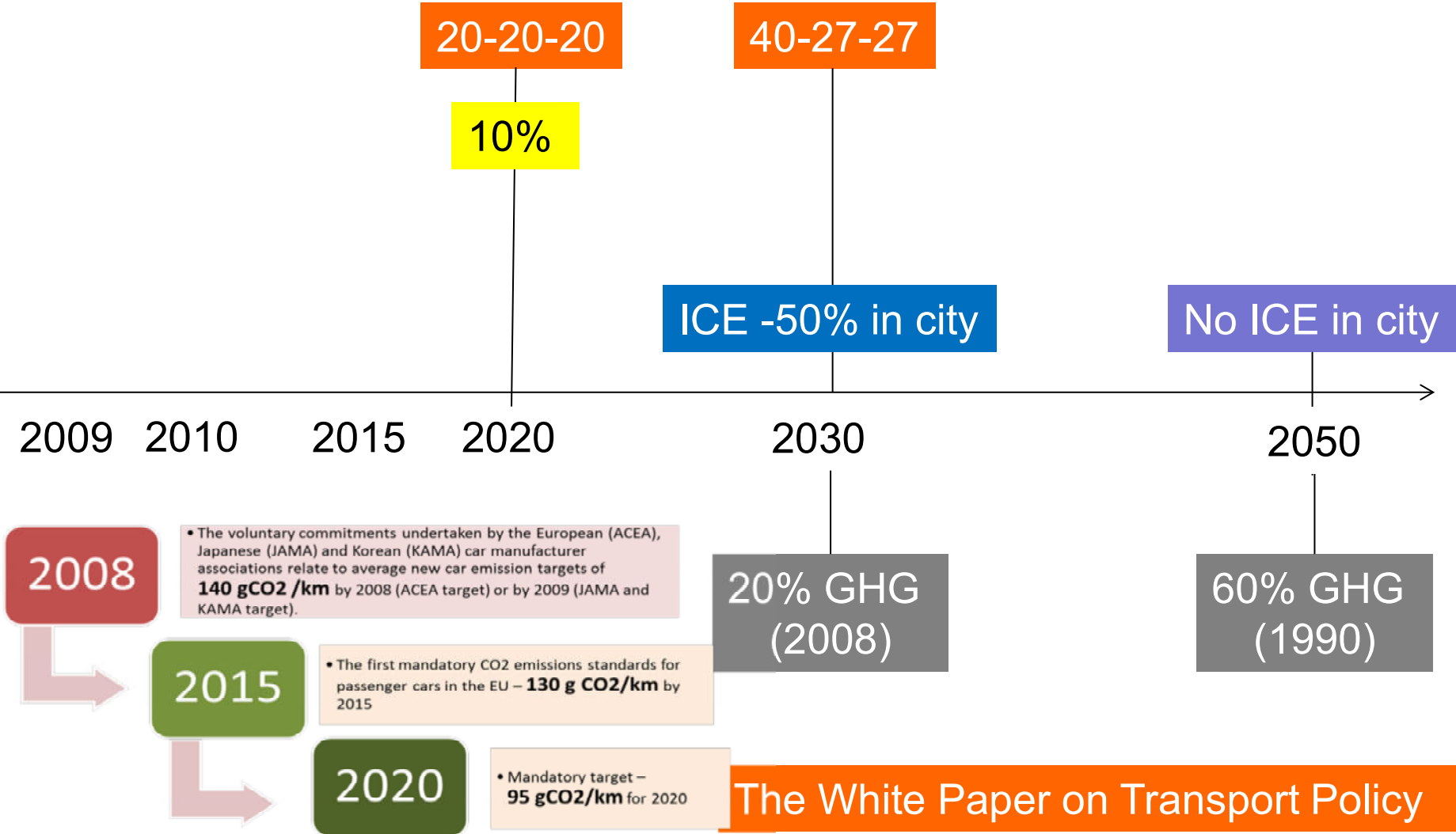
EU-28: Final energy consumption

26%   33%

Transport

Non-Transport   Transport

GHG emissions by sectrors: EU-28

Eurostat
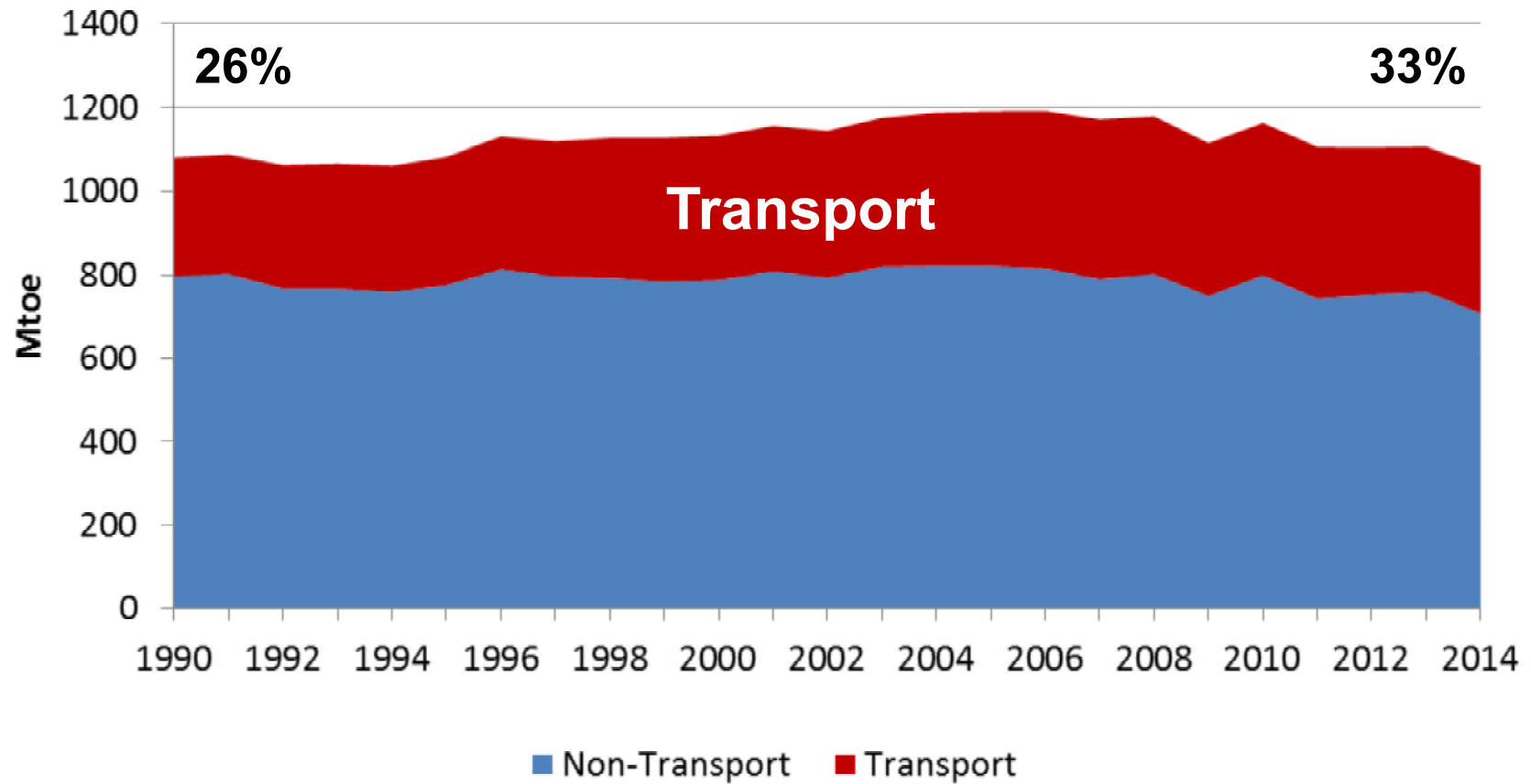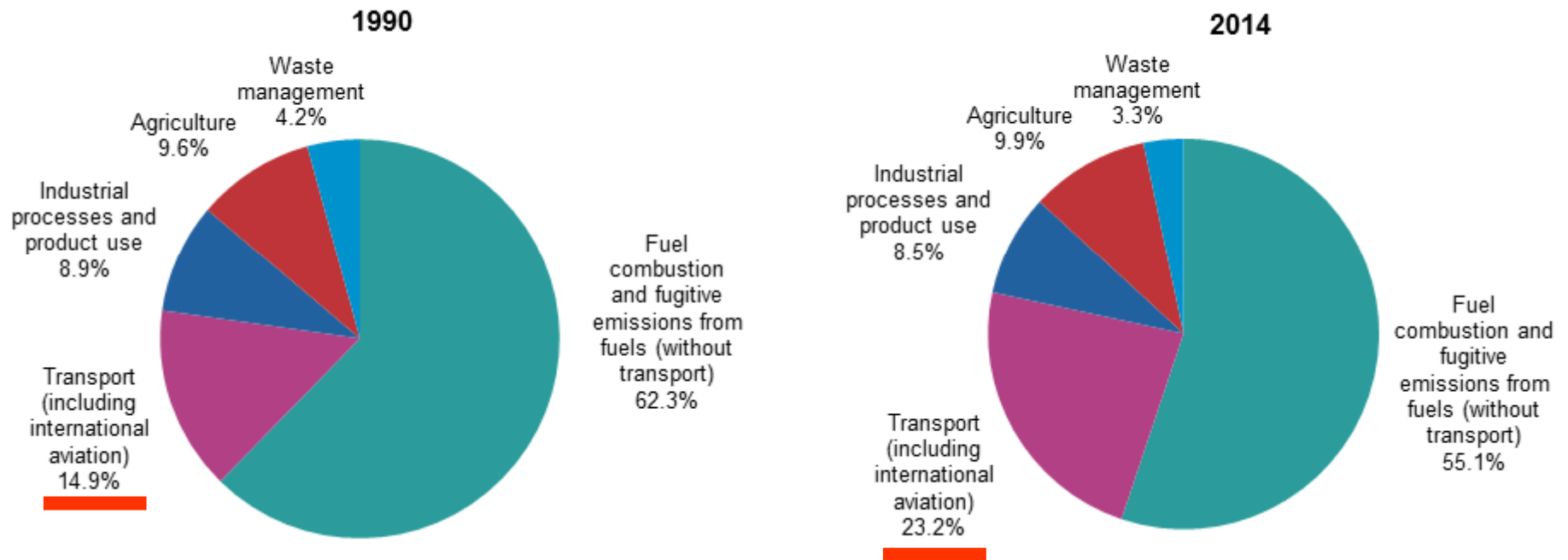
GHG emissions by sector

EU policies and targets

Alternative fuels

Mature AEC
Electricity

1st gen. biofuels:

Bioethanol
Biodiesel

Inmature AEC
2nd gen. biofuels:
Bioethanol from Lignocellulose

Hydrogen

AEC in labour stage
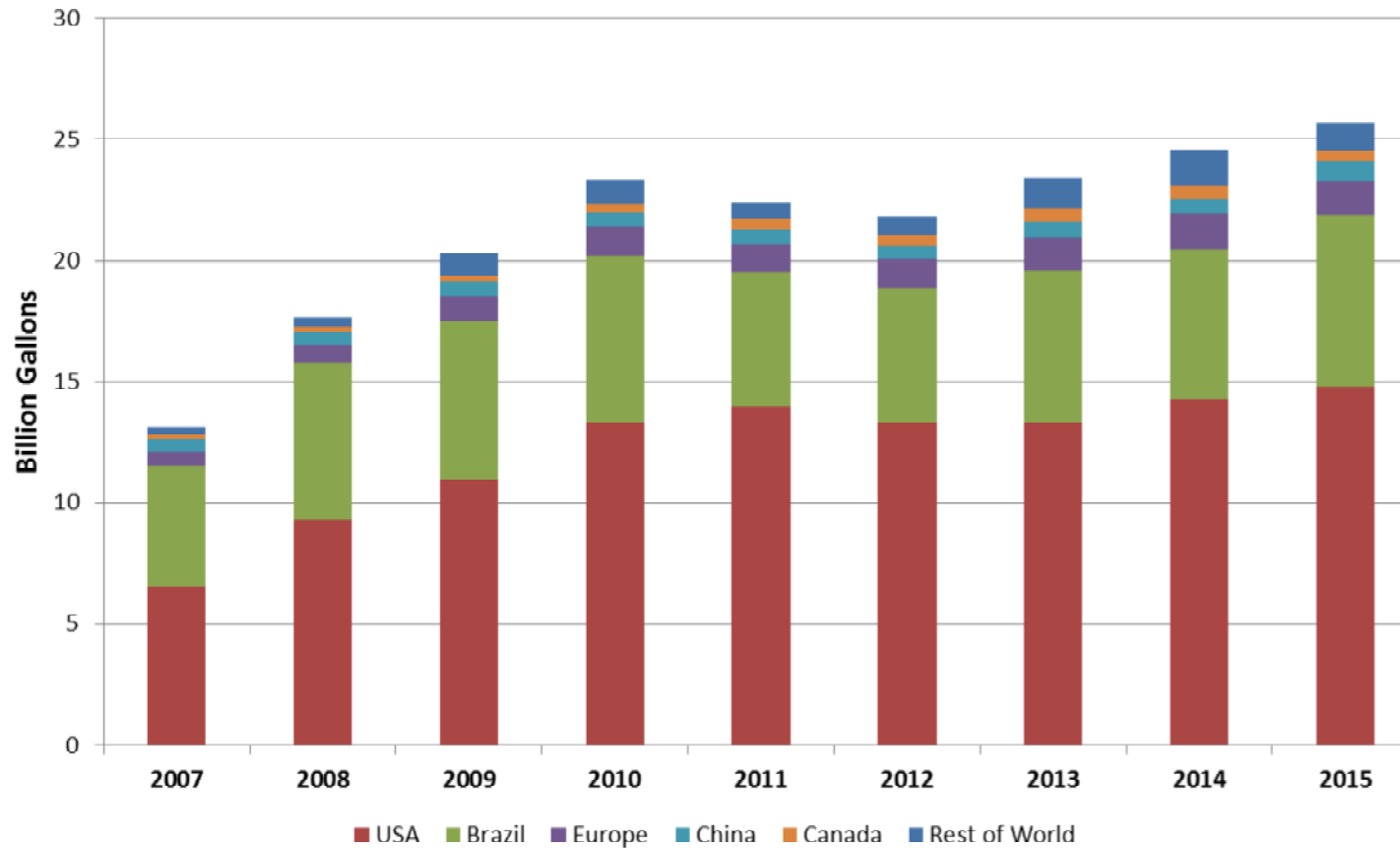*3td gen. biofuels:*
Ethanol from algae
…

Technology suprise
4th gen.biofuels

…

Bioethanol

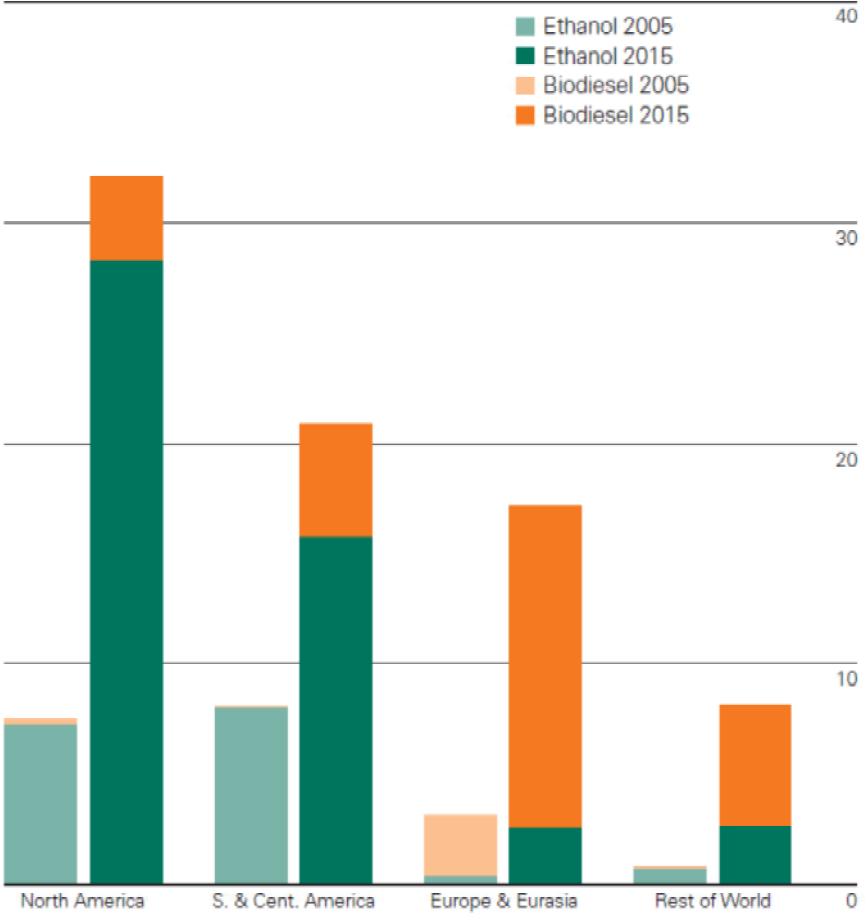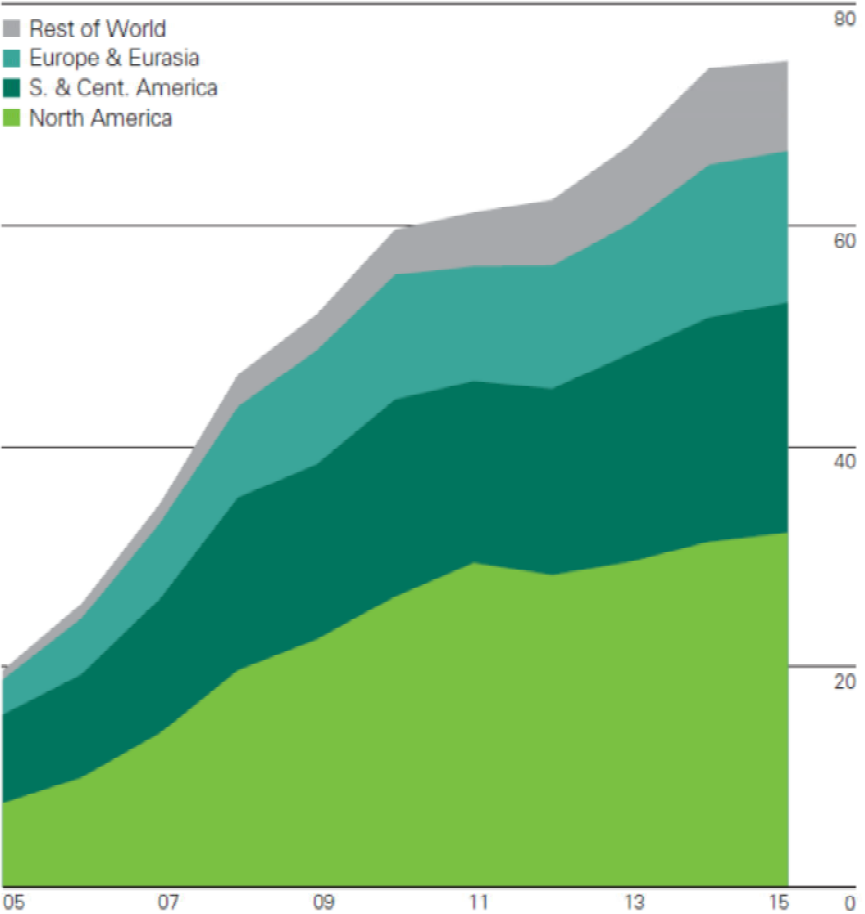**Global Ethanol Production by Country/Region and Year**

Biofuel

World biofuels production
Million tonnes oil equivalent

Legend (left chart):
- Rest of World
- Europe & Eurasia
- S. & Cent. America
- North America

Legend (right chart):
- Ethanol 2005
- Ethanol 2015
- Biodiesel 2005
- Biodiesel 2015

Right chart categories: North America, S. & Cent. America, Europe & Eurasia, Rest of World
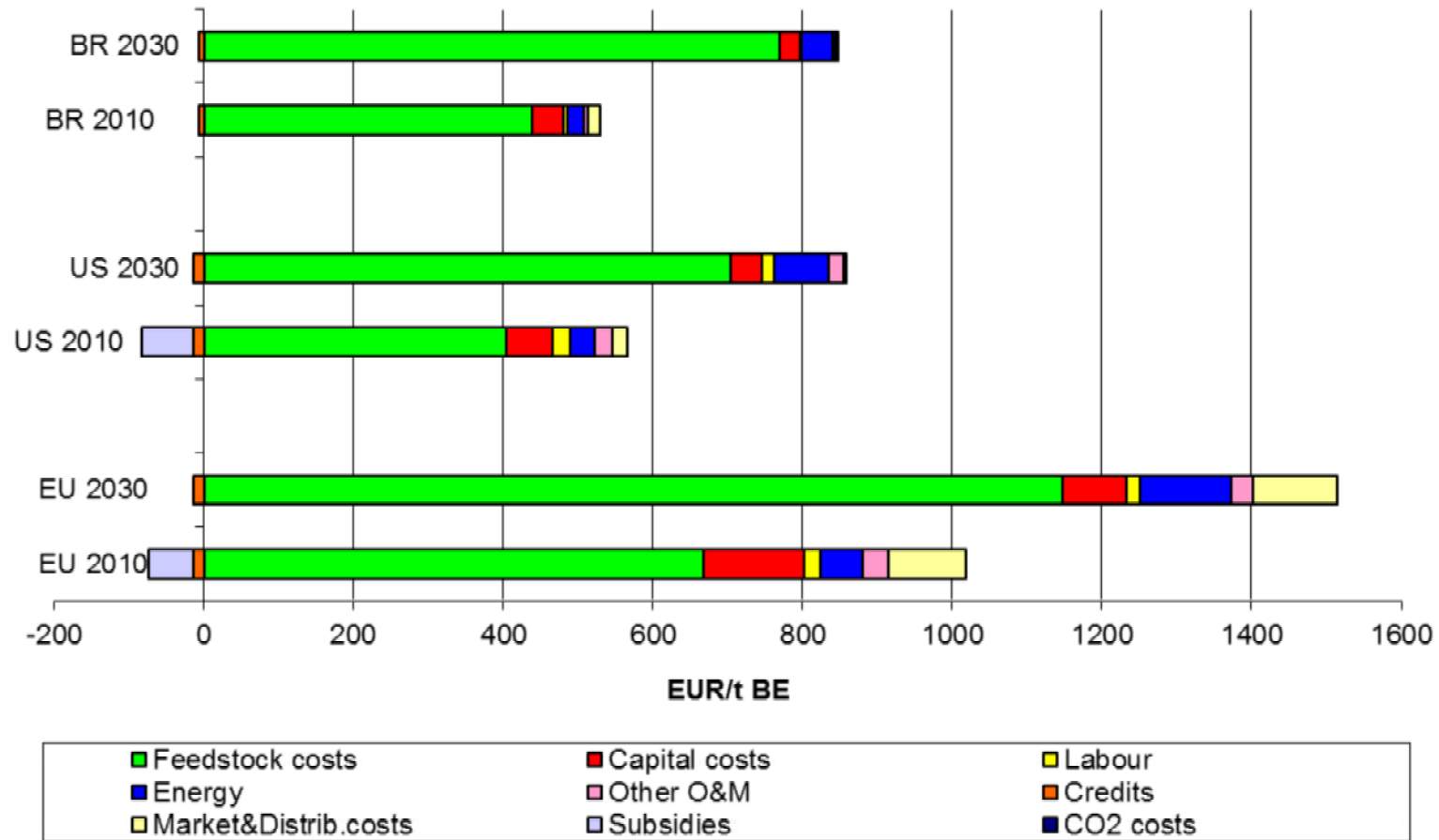
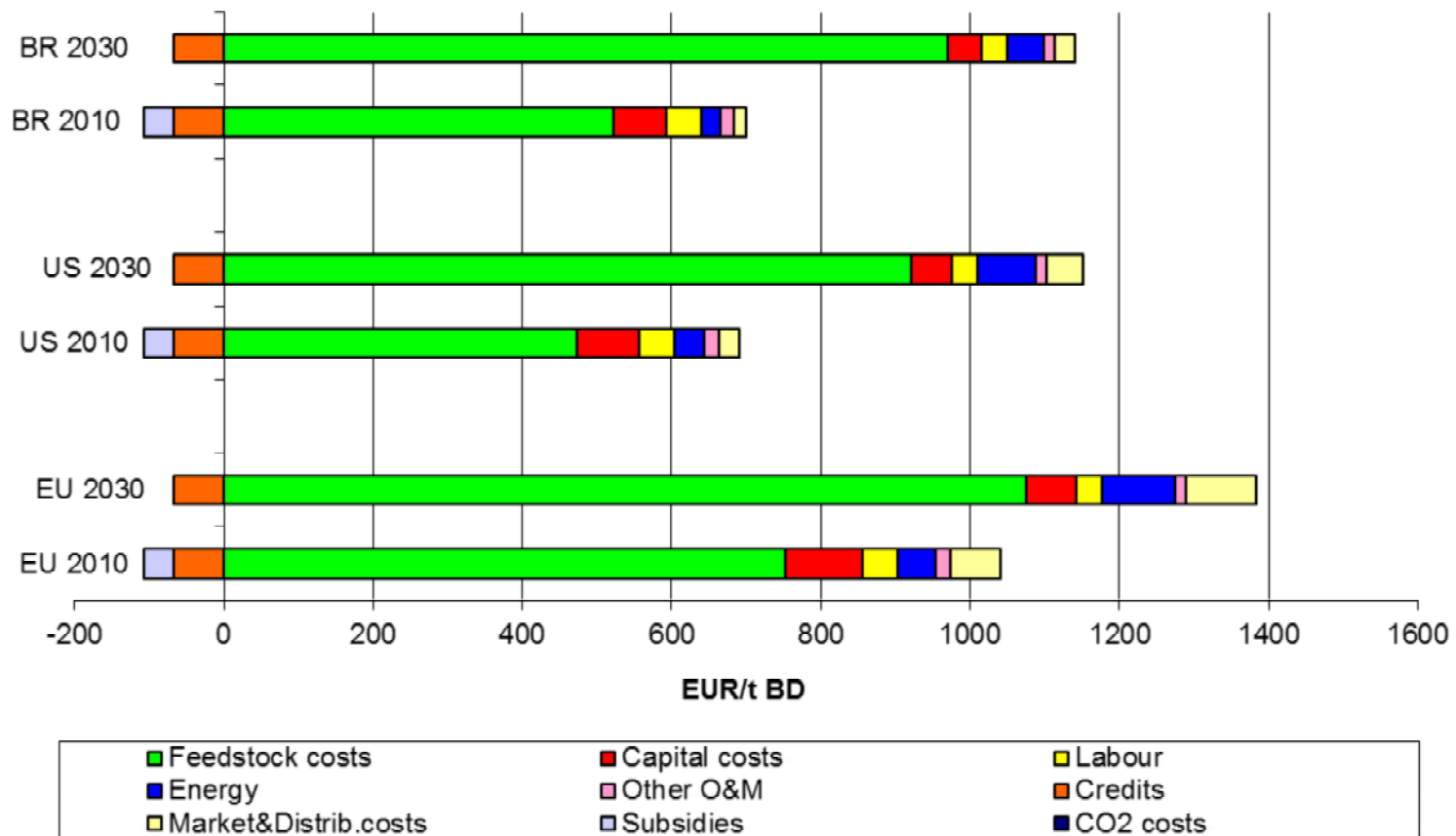# Share of biofuels in total road-fuel consumption in energy terms
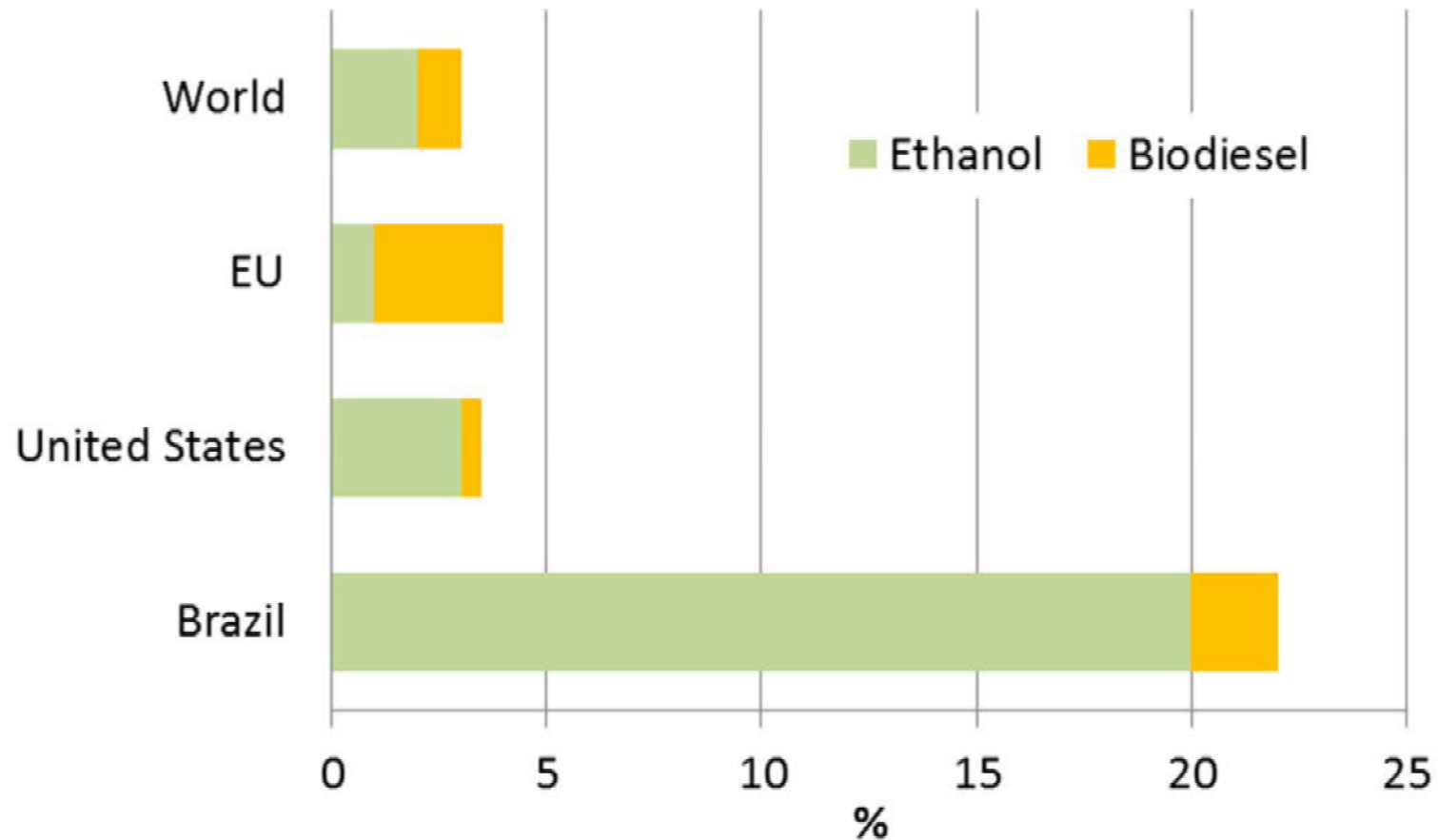
Source: F.O.Licht,IEA 2009
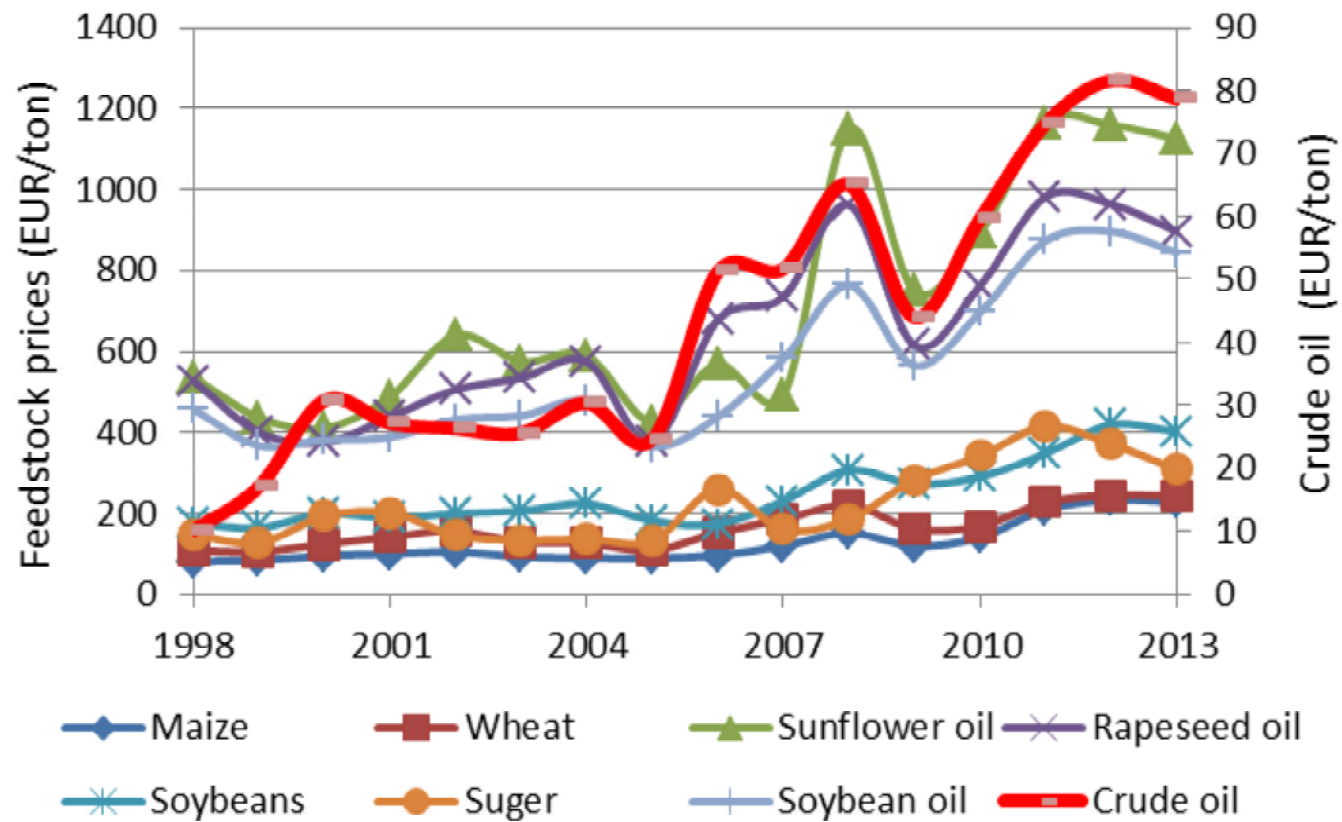
Bioethanol production costs

Comparison of bioethanol production costs in the US, Brazil and the EU (average) in 2010 and 2030 (prices of 2010)
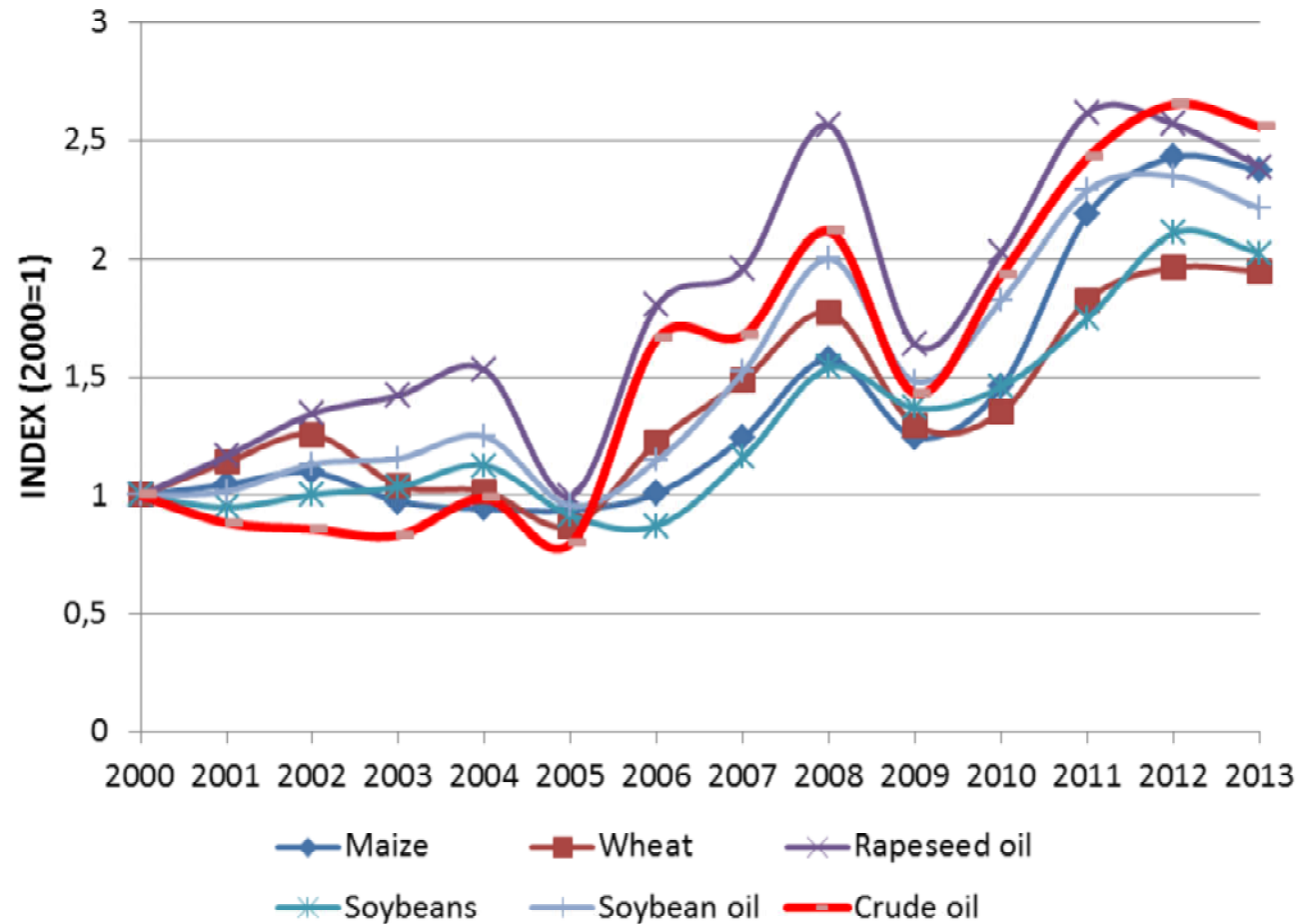
Biodiesel production costs

Comparison of biodiesel production costs in the US, Brazil and the EU (average) in 2010 and 2030 (prices of 2010)
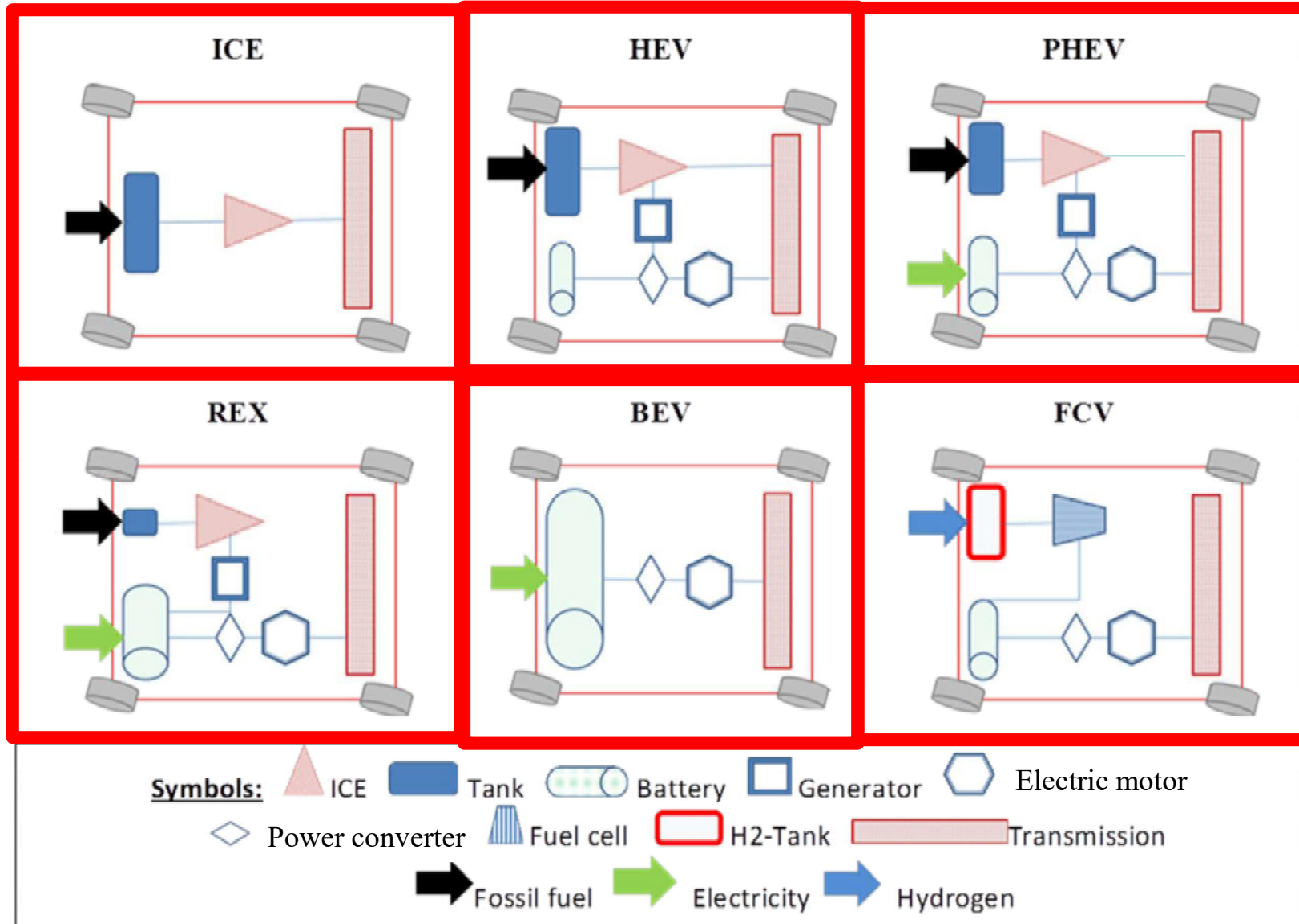
Feedstock prices

Feedstock and crude oil prices for the period 1998-2013
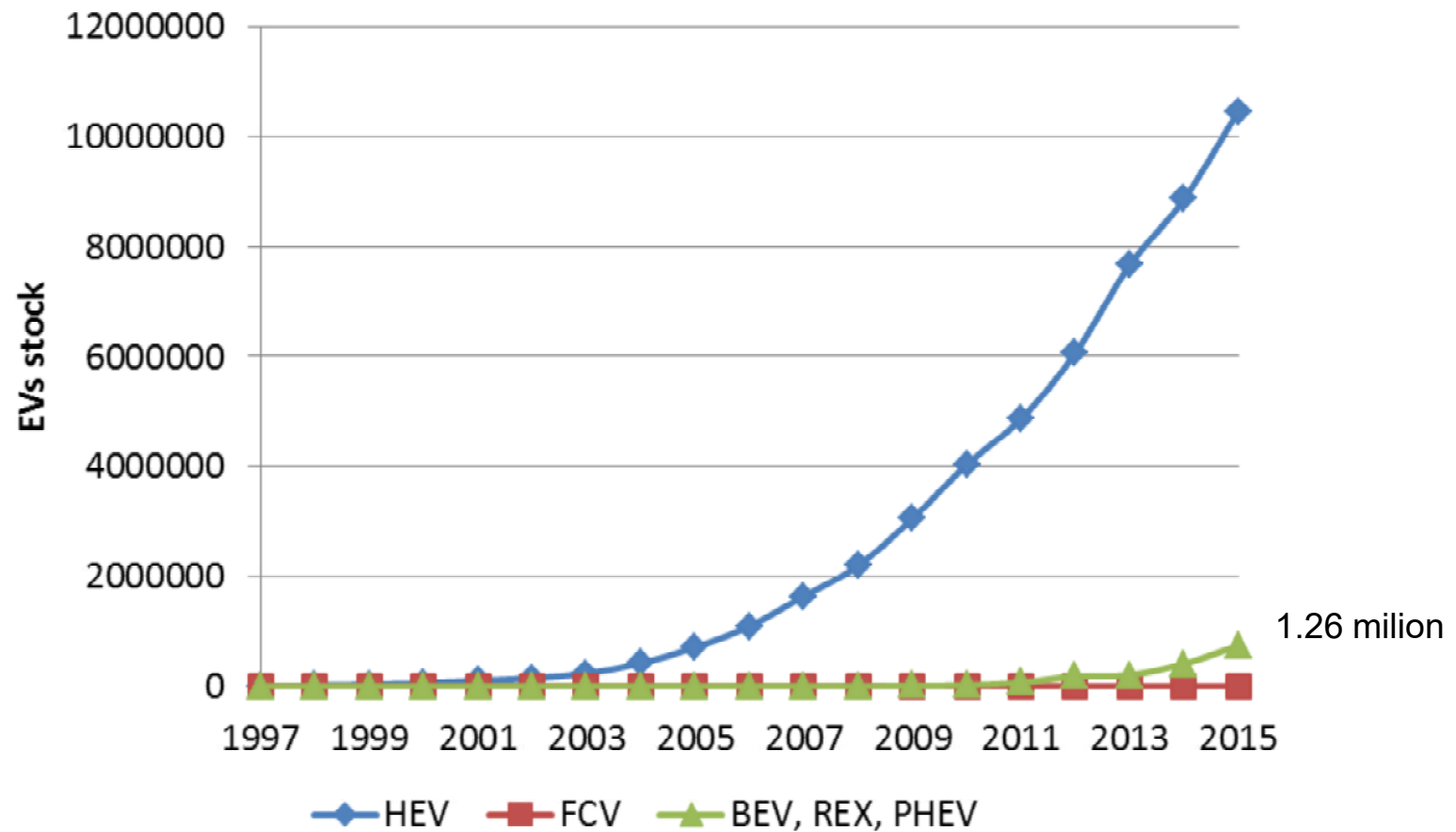
Feedstock prices

Normalized development of feedstock and crude oil prices for the period 2000-2013
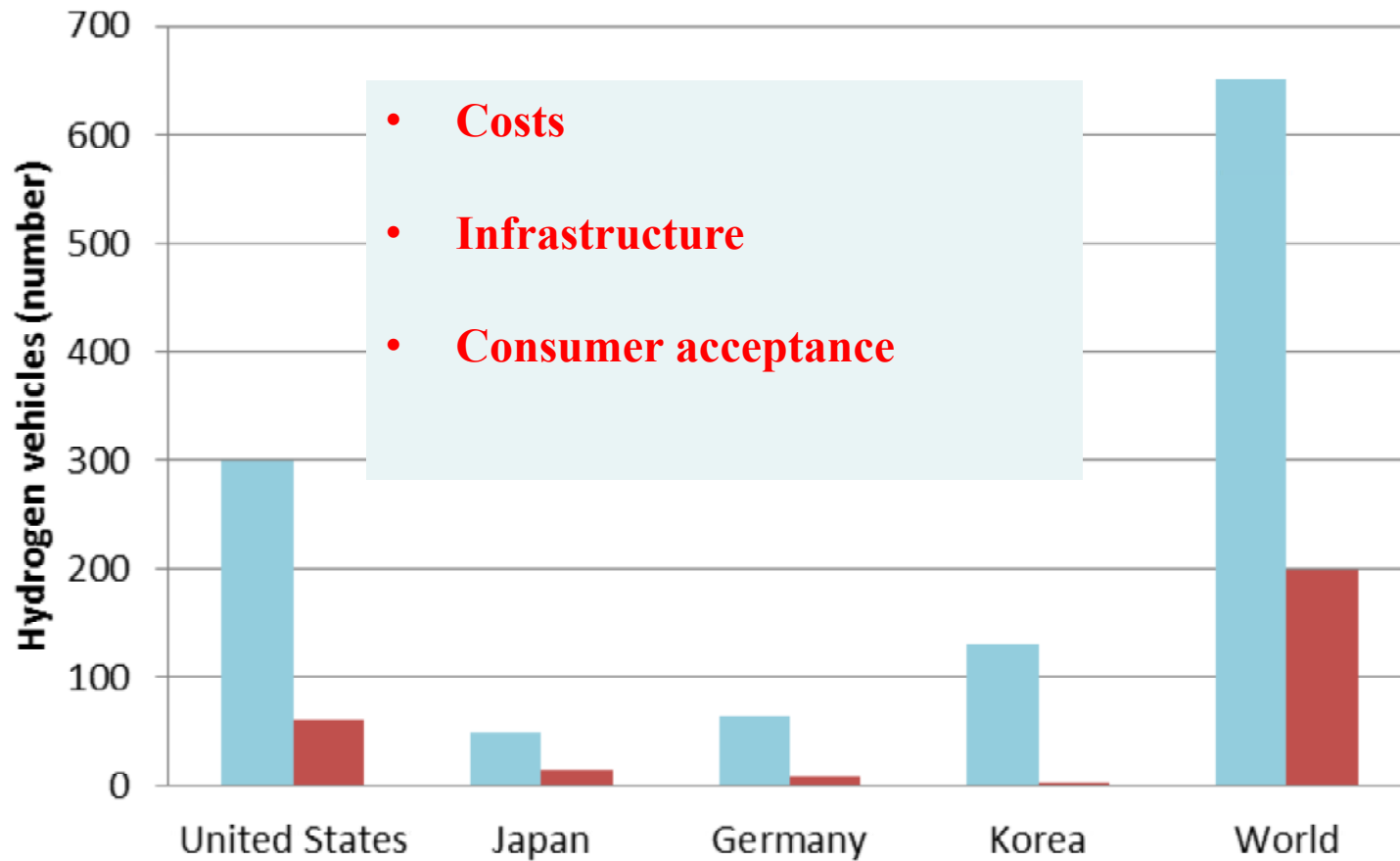(Index 2000=1)

Electric vehicles

Electric vehicles

Development of the global stock of EVs

Targets

Paris Declaration on Electro-Mobility and Climate Change & Call to Action:

- more than 100 million EVs

- 400 million two and three-wheelers

Fuel cell vehicles

- Costs
- Infrastructure
- Consumer acceptance

Total stock of hydrogen FCV in today's leading countries and worldwide

Economic assessment

The costs per km driven C_{km} are calculated as:

$$C_{km} = \frac{IC \cdot \alpha}{skm} + P_f \cdot FI + \frac{C_{O\&M}}{skm} \qquad \text{[€/100 km driven]}$$

IC……investment costs [€/car]
α……..capital recovery factor
skm…..specific km driven per car per year [km/(car.yr)]
Pf……..fuel price incl. taxes [€/litre]
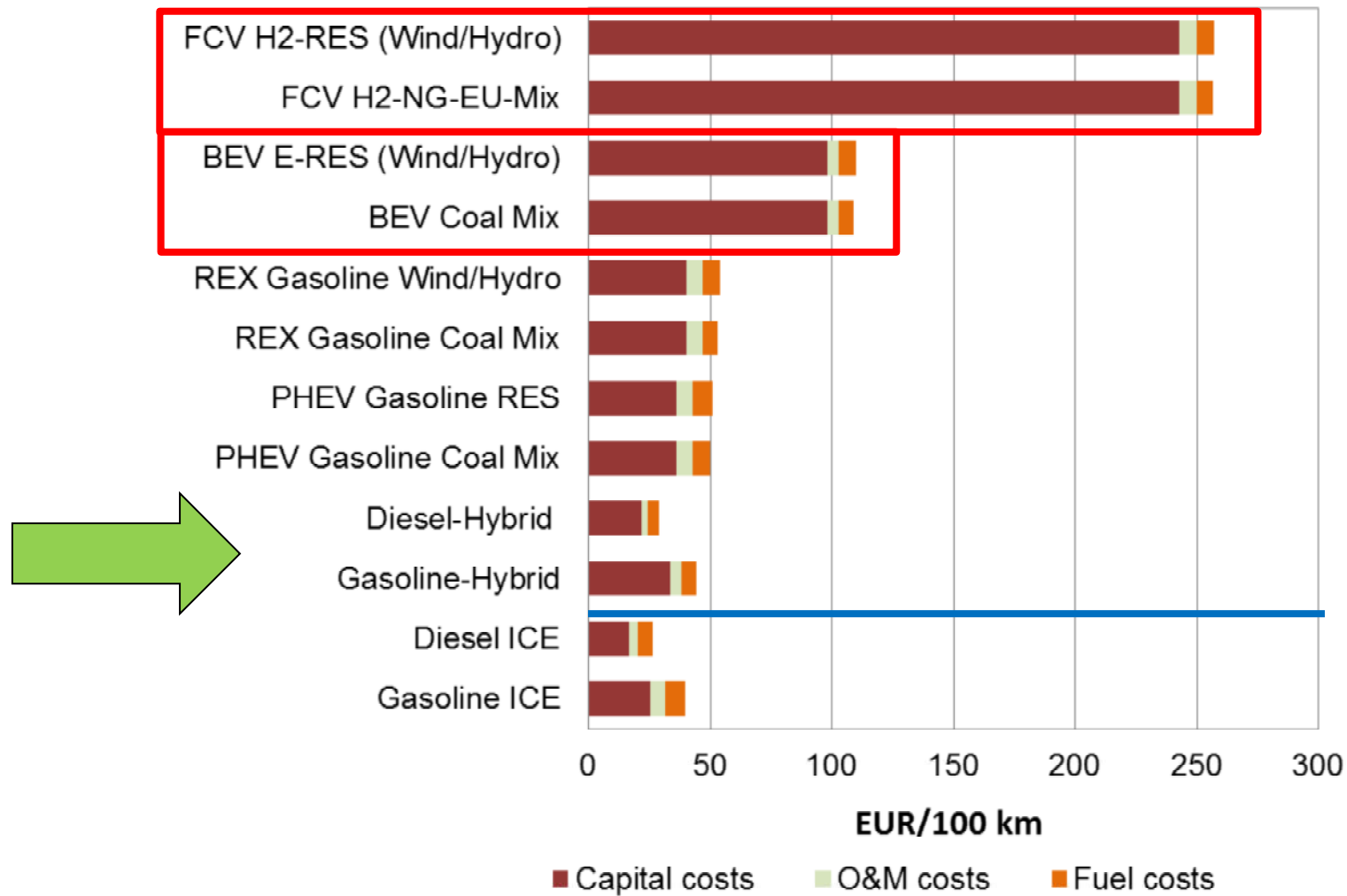$C_{O\&M}$…operating and maintenance costs
FI……..fuel intensity [litre/100 km]

A capital recovery factor (α) is the ratio of a constant annuity to the present value of receiving that annuity for a given length of time. Using an interest rate (z), the capital recovery factor is:

$$\alpha = \frac{z(1+z)^n}{(1+z)^n - 1}$$

n…..the number of annuities received.
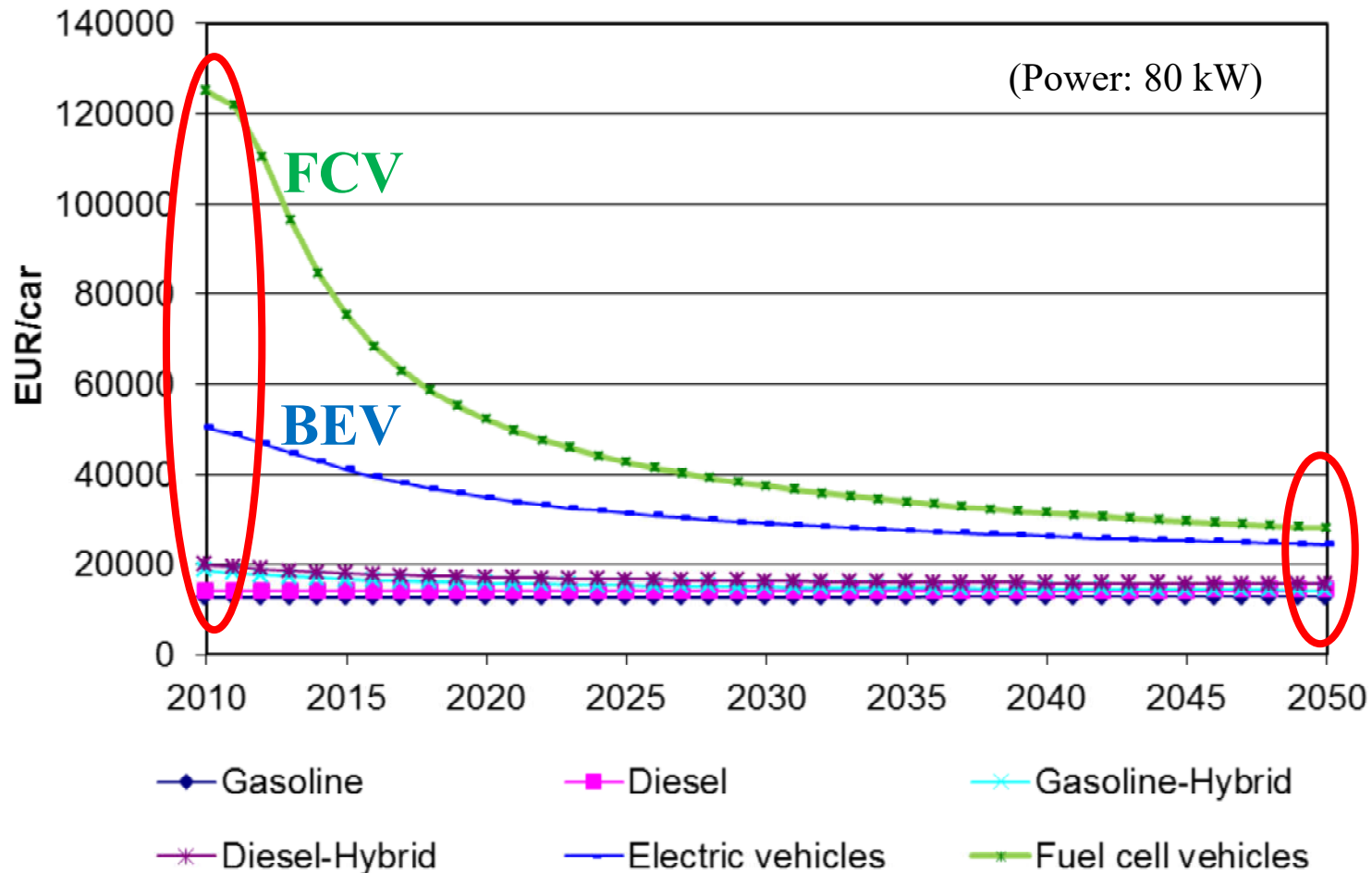
Total costs of service mobility

Chart: Total costs of service mobility (EUR/100 km) broken down by Capital costs, O&M costs, and Fuel costs for various vehicle types:

- FCV H2-RES (Wind/Hydro)
- FCV H2-NG-EU-Mix
- BEV E-RES (Wind/Hydro)
- BEV Coal Mix
- REX Gasoline Wind/Hydro
- REX Gasoline Coal Mix
- PHEV Gasoline RES
- PHEV Gasoline Coal Mix
- Diesel-Hybrid
- Gasoline-Hybrid
- Diesel ICE
- Gasoline ICE

EUR/100 km

Legend: Capital costs, O&M costs, Fuel costs

Scenario for development of investment costs

Technological learning:

$$C_t(x) = a \cdot x_t^{-b}$$

a............specific costs of the first unit
b............learning rate
x ....cumulative (unit) production

(Power: 80 kW)

FCV

BEV

EUR/car

Legend:
- Gasoline
- Diesel
- Gasoline-Hybrid
- Diesel-Hybrid
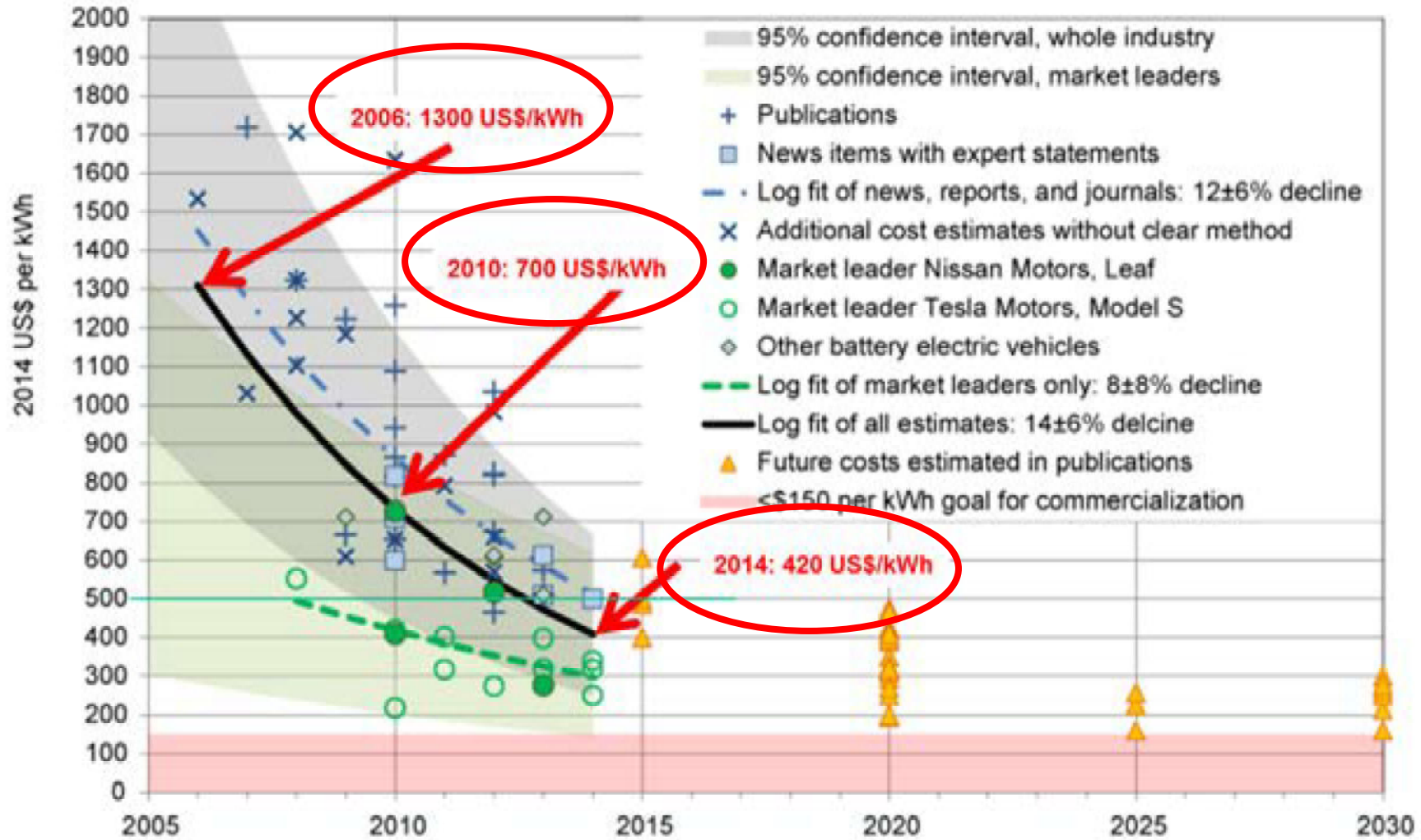- Electric vehicles
- Fuel cell vehicles

Costs of electric vehicles
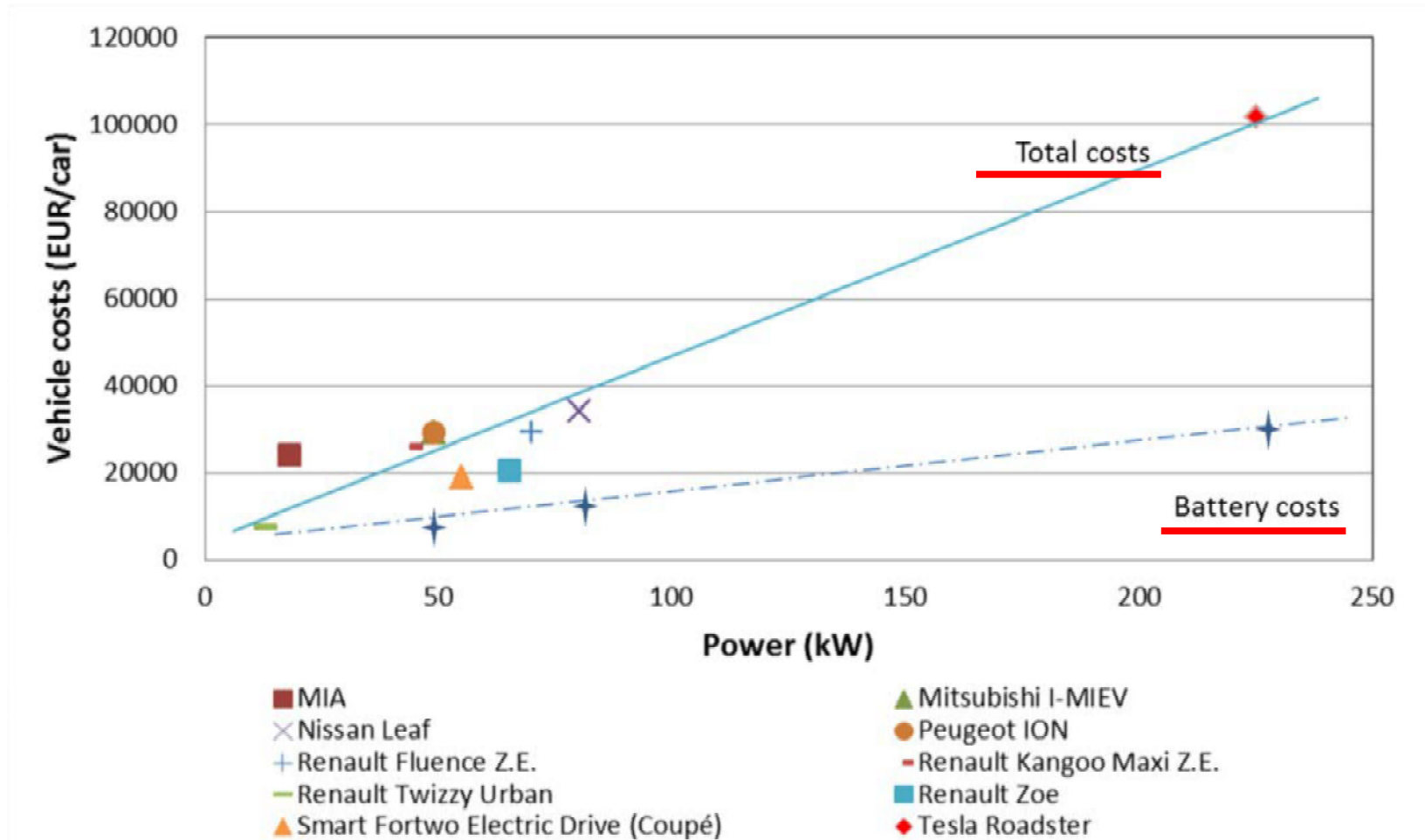
Total investment and battery costs of selected BEVs related to power of car

Technological learning – Battery

Monetary measures

In Europe, the most commonly used monetary measures are subsidies and exemptions (or reductions) from:

➢ road taxes (e.g., in DE, DK, CZ)
➢ annual circulation tax (e.g., in DE, GR, NO, SE,UK)
➢ company car tax (e.g., in FR, UK)
➢ registration tax (e.g., in NO, BE,DE, FI, NL)
➢ fuel consumption tax (e.g., in AT)
➢ congestion charges (e.g., in NO, SE, UK)

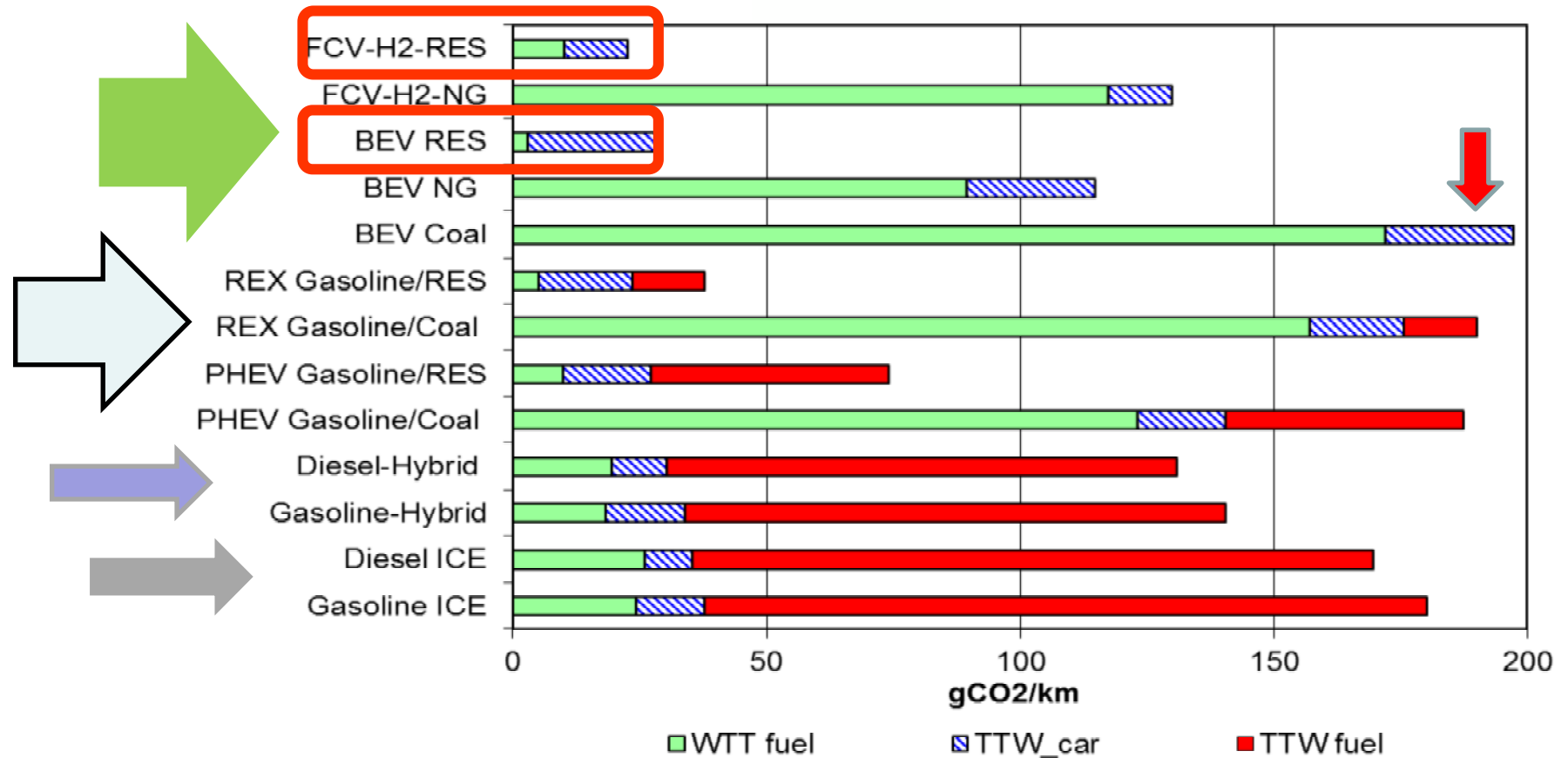# *Non-monetary measures*

The most important non-monetary measures are:

➢ free parking spaces,

➢ possibility for EVs drivers to use bus lanes,

➢ wide availability of charging stations,

➢ permission for EVs to enter city centers and zero emission zones.
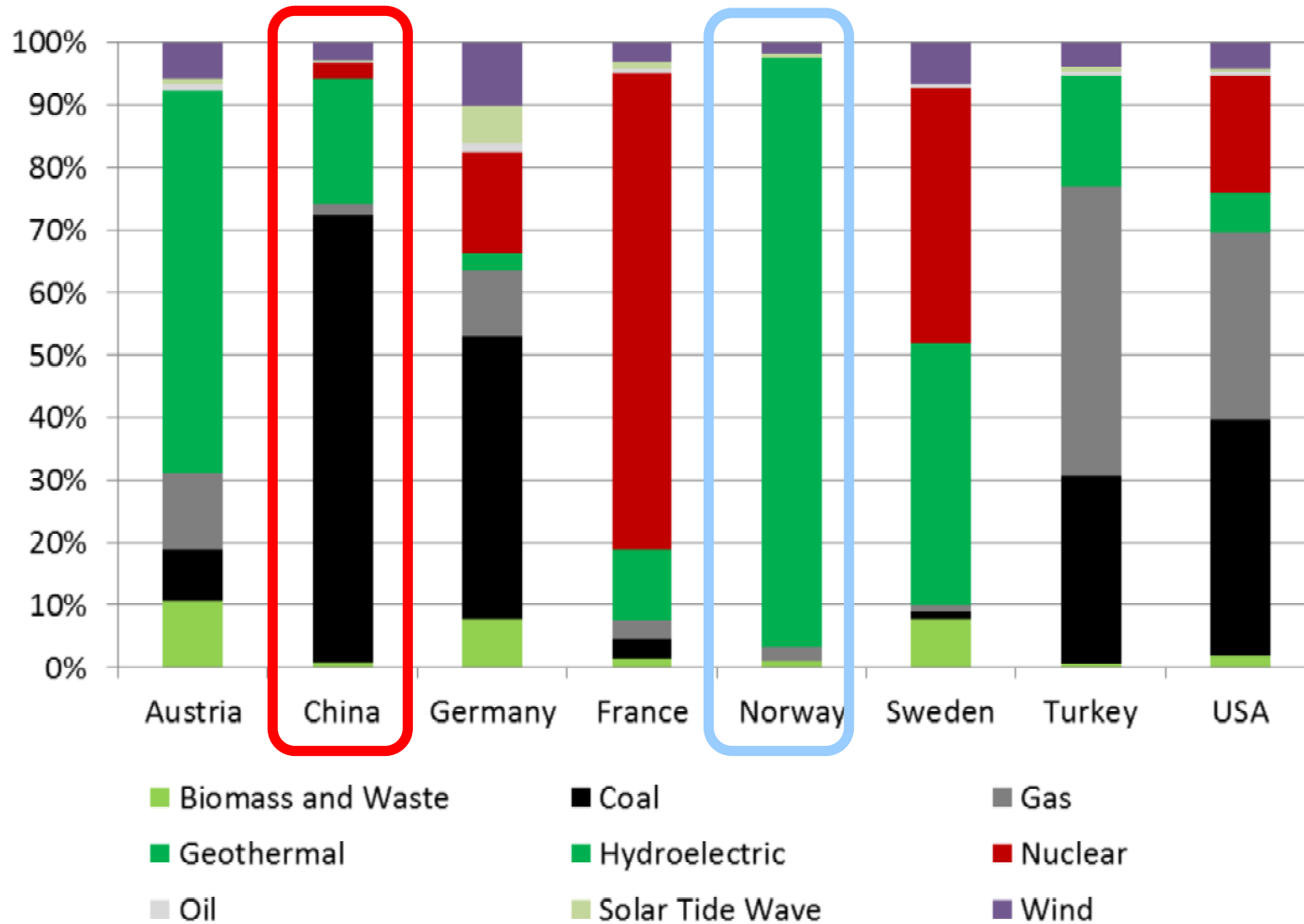
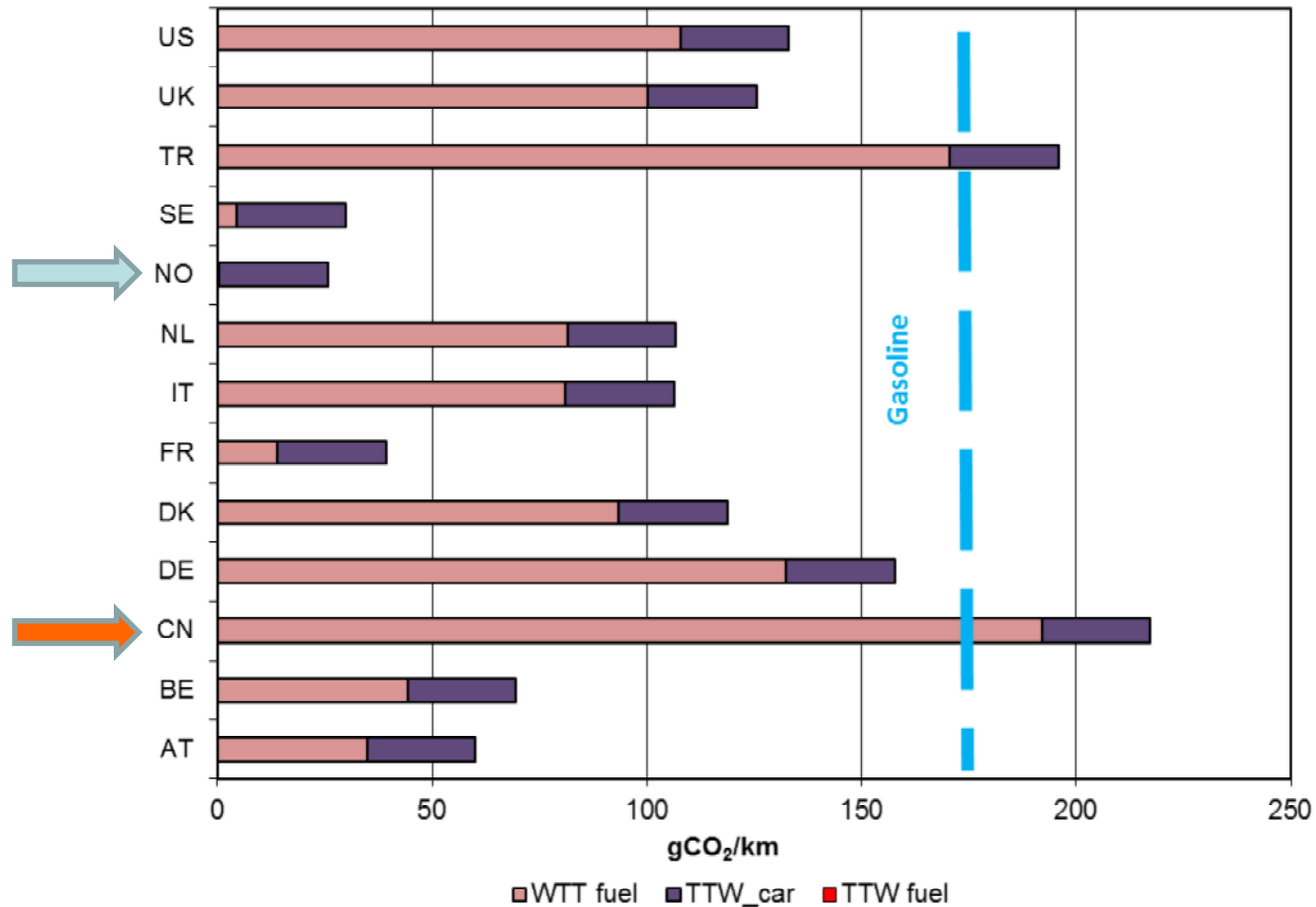# Environmental assessment
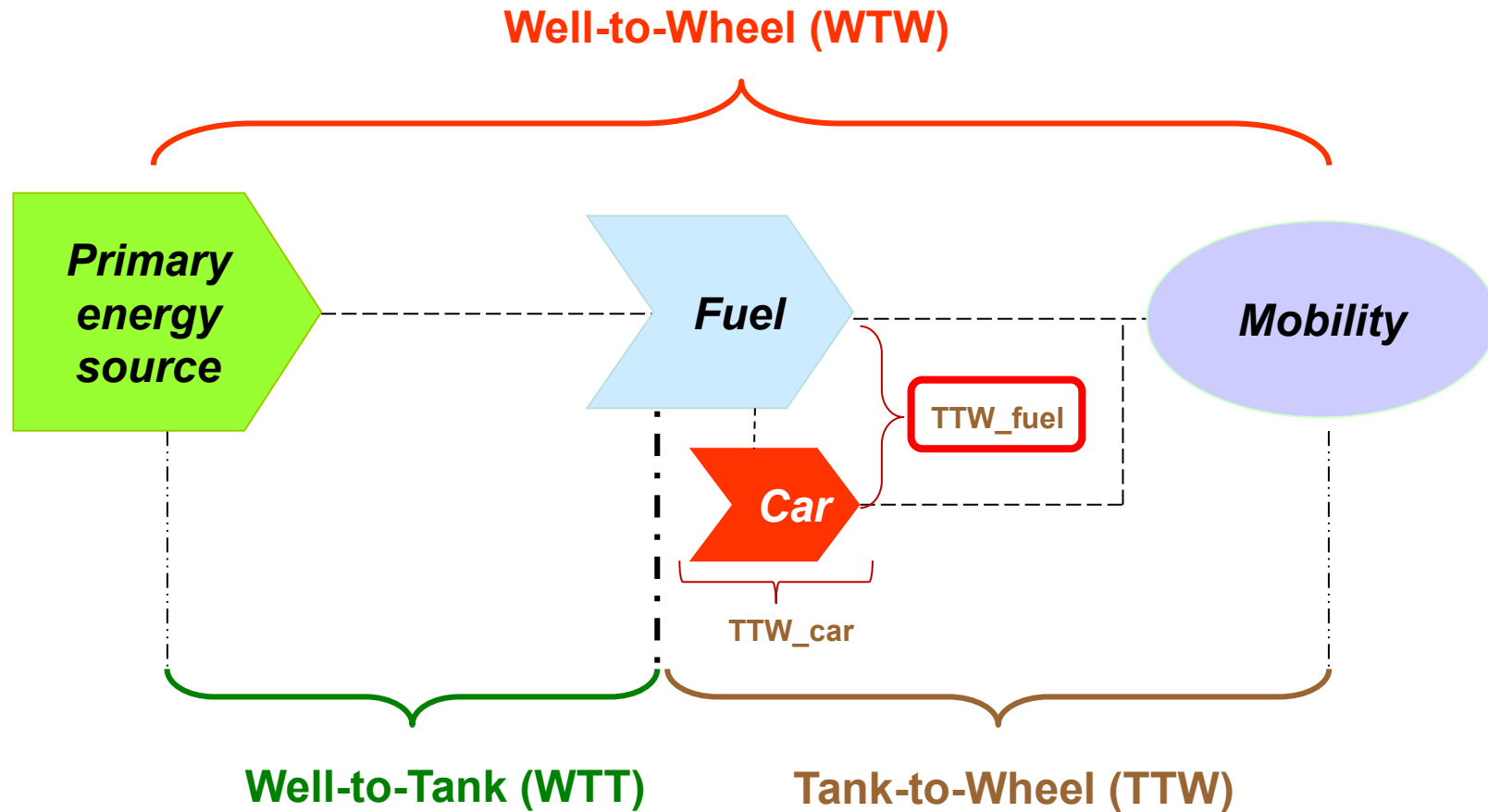
Environmental assessment

CO$_2$ emissions per km driven for various types of EV in comparison to conventional cars (power of car: 80kW)
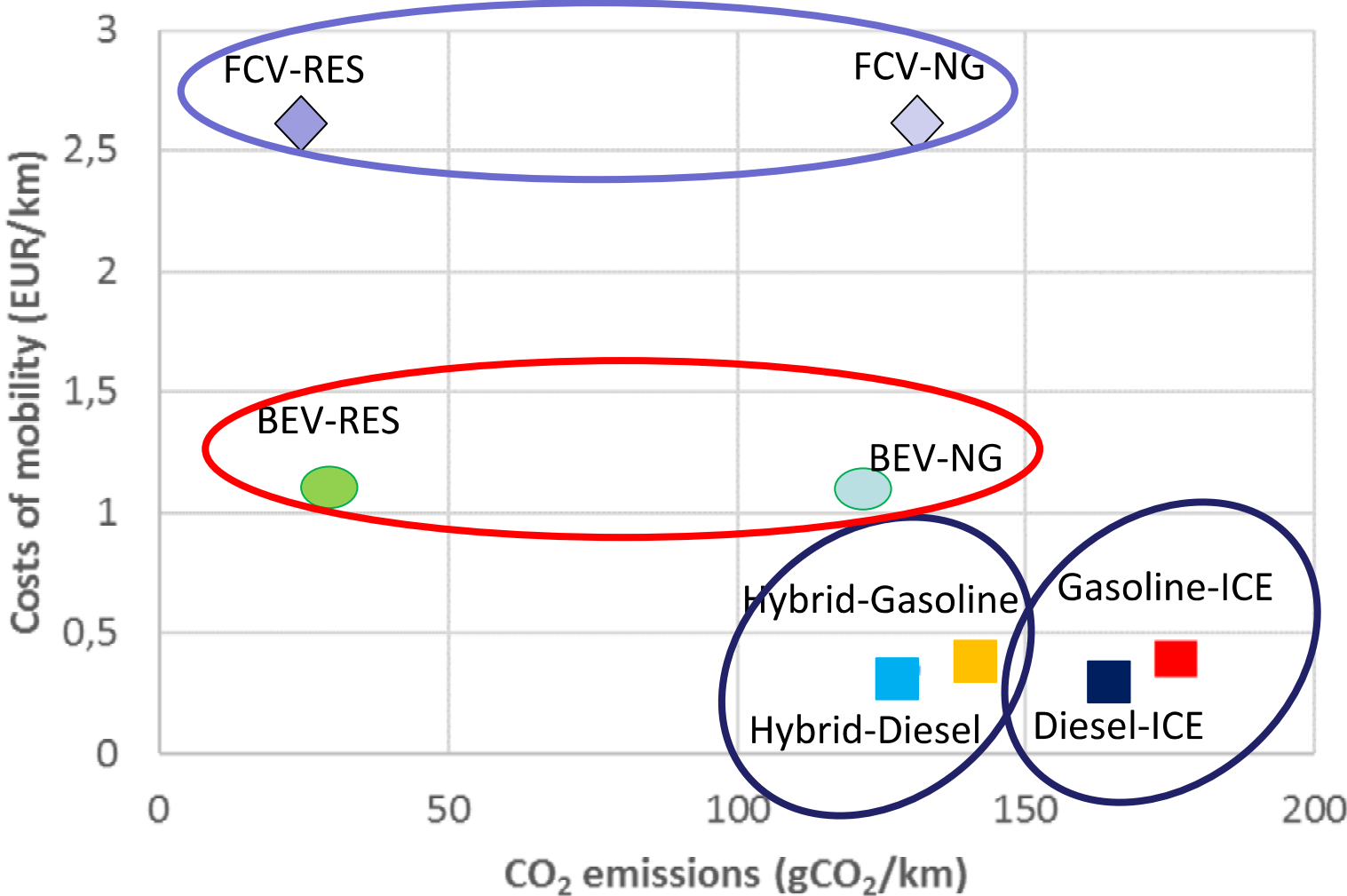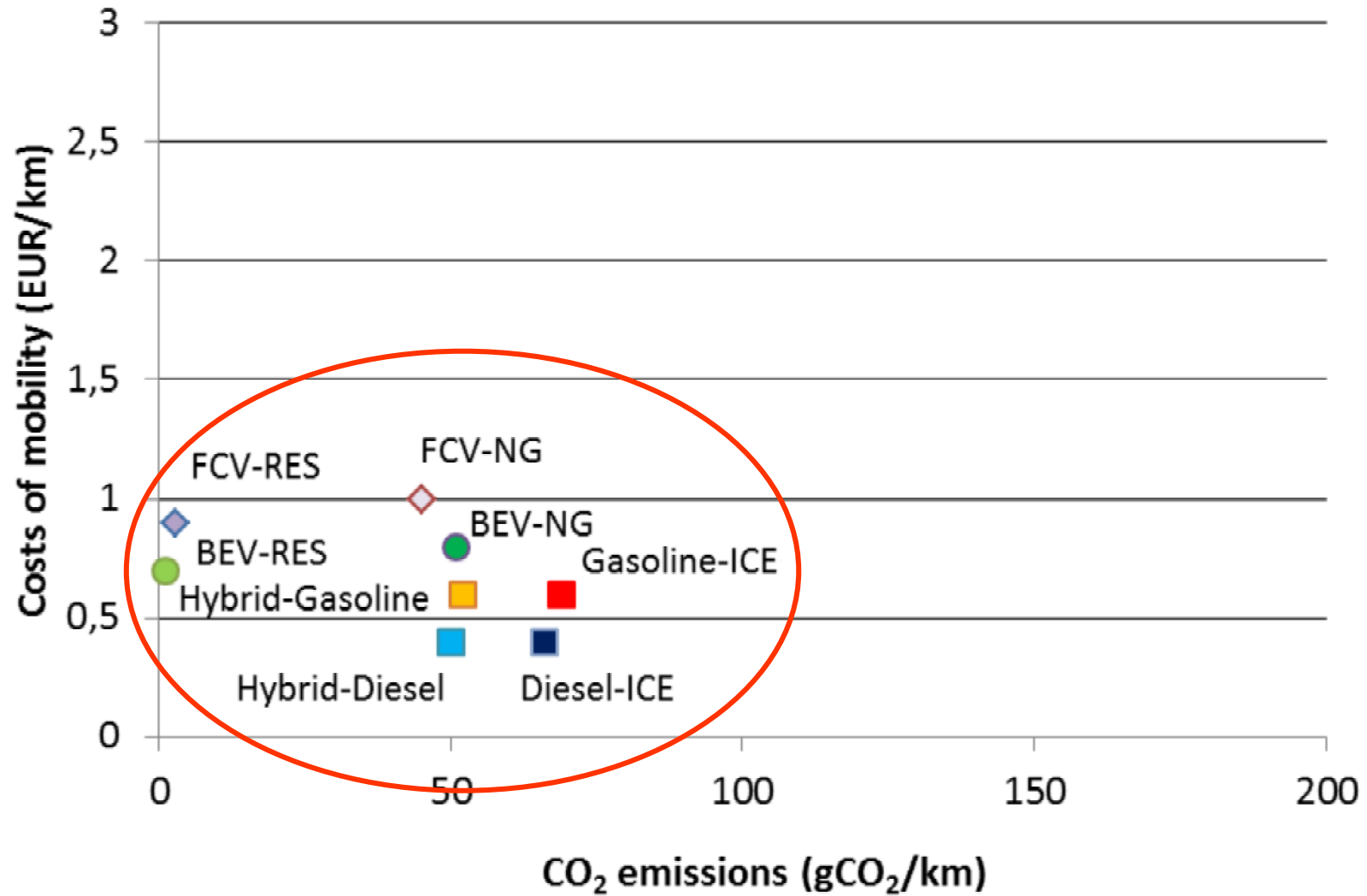
Electricity mix (2014)

Data source: tsp,2014

Environmental assessment

CO_2 emissions per km driven for BEVs powered by grid electricity in different countries
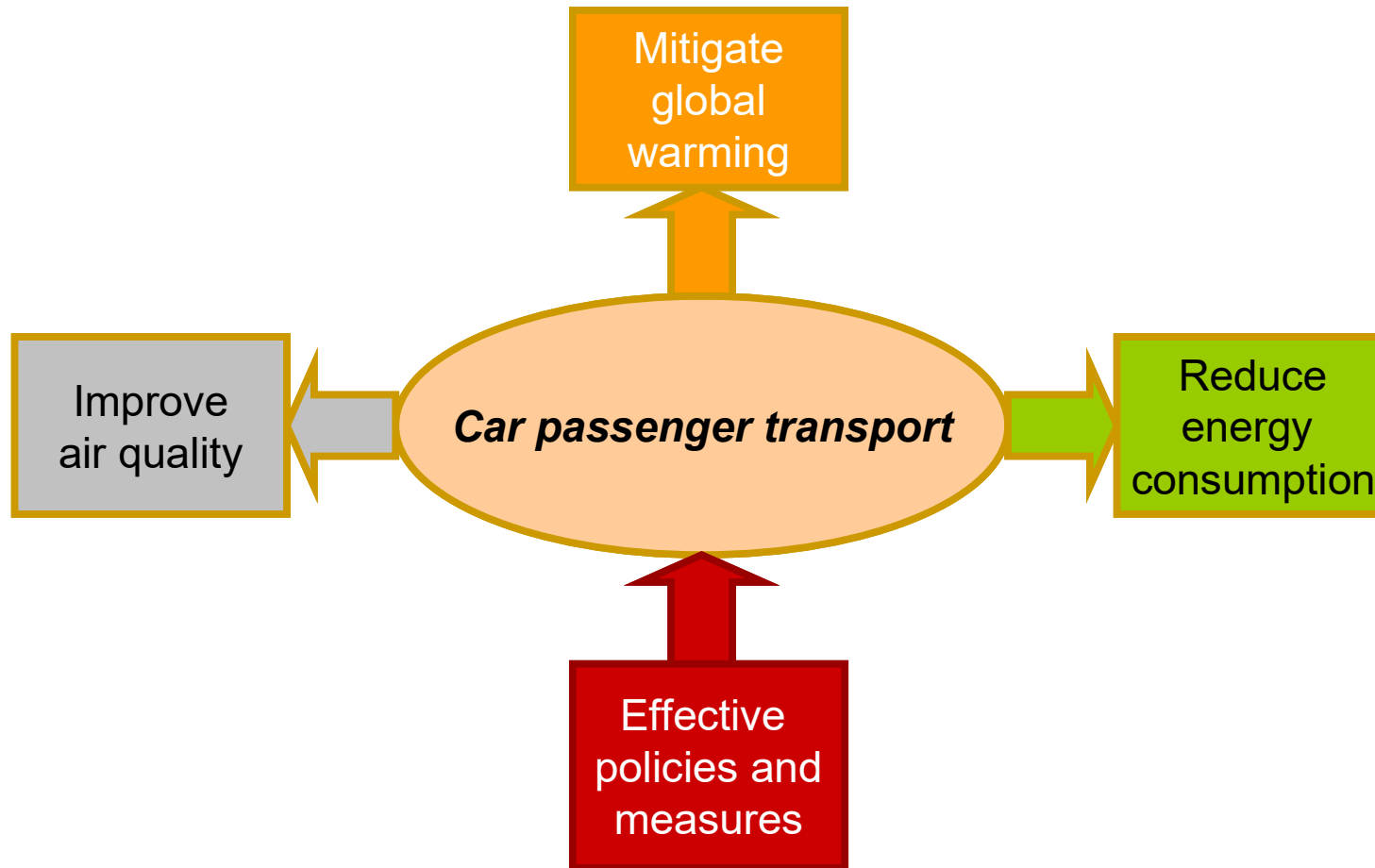
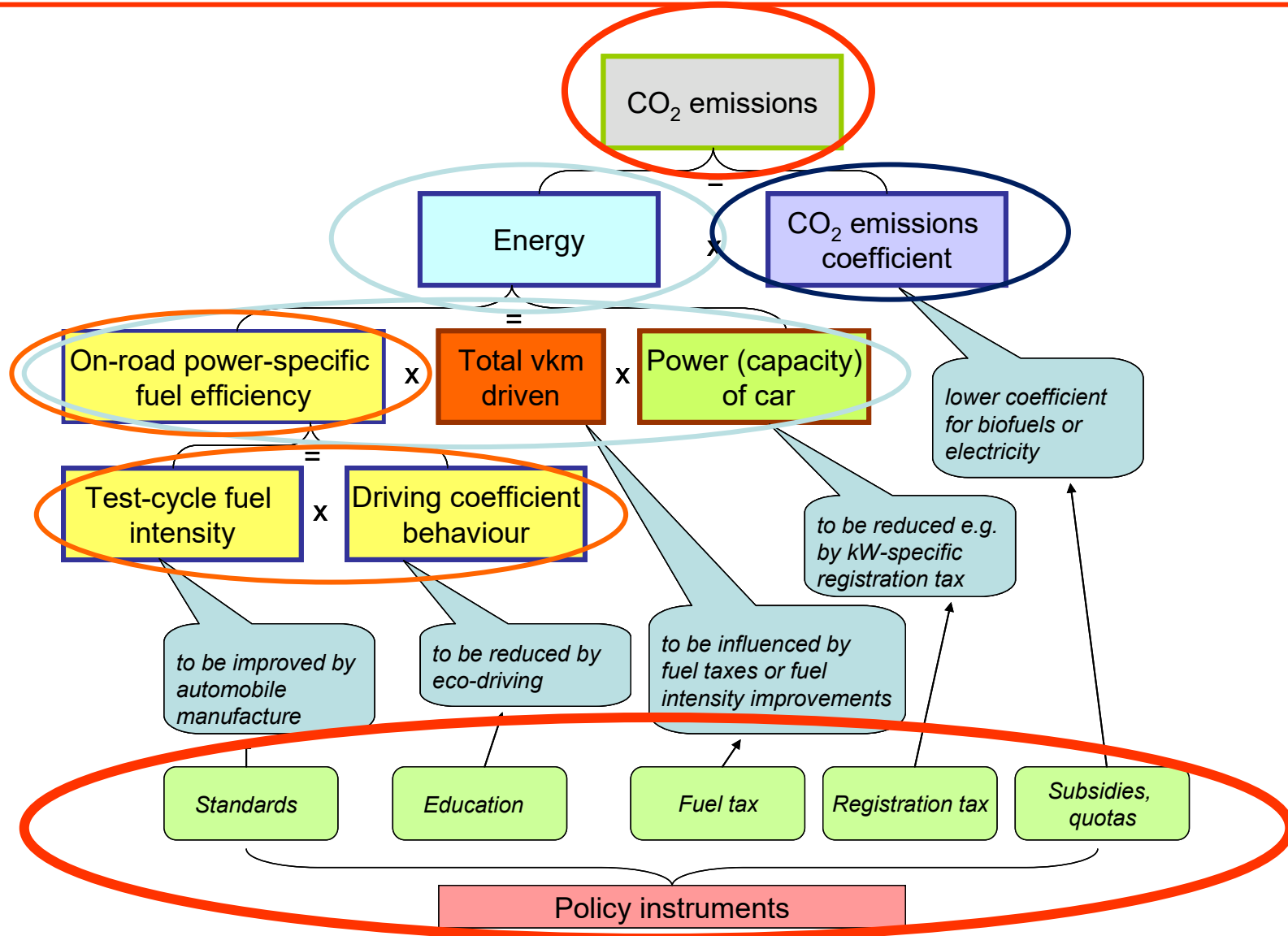**CO_2 emissions vs. driving costs: 2012**

CO$_2$ emissions vs. driving costs: 2050

5. Energy policies

Energy policy

Mitigate global warming

Improve air quality

Car passenger transport

Reduce energy consumption
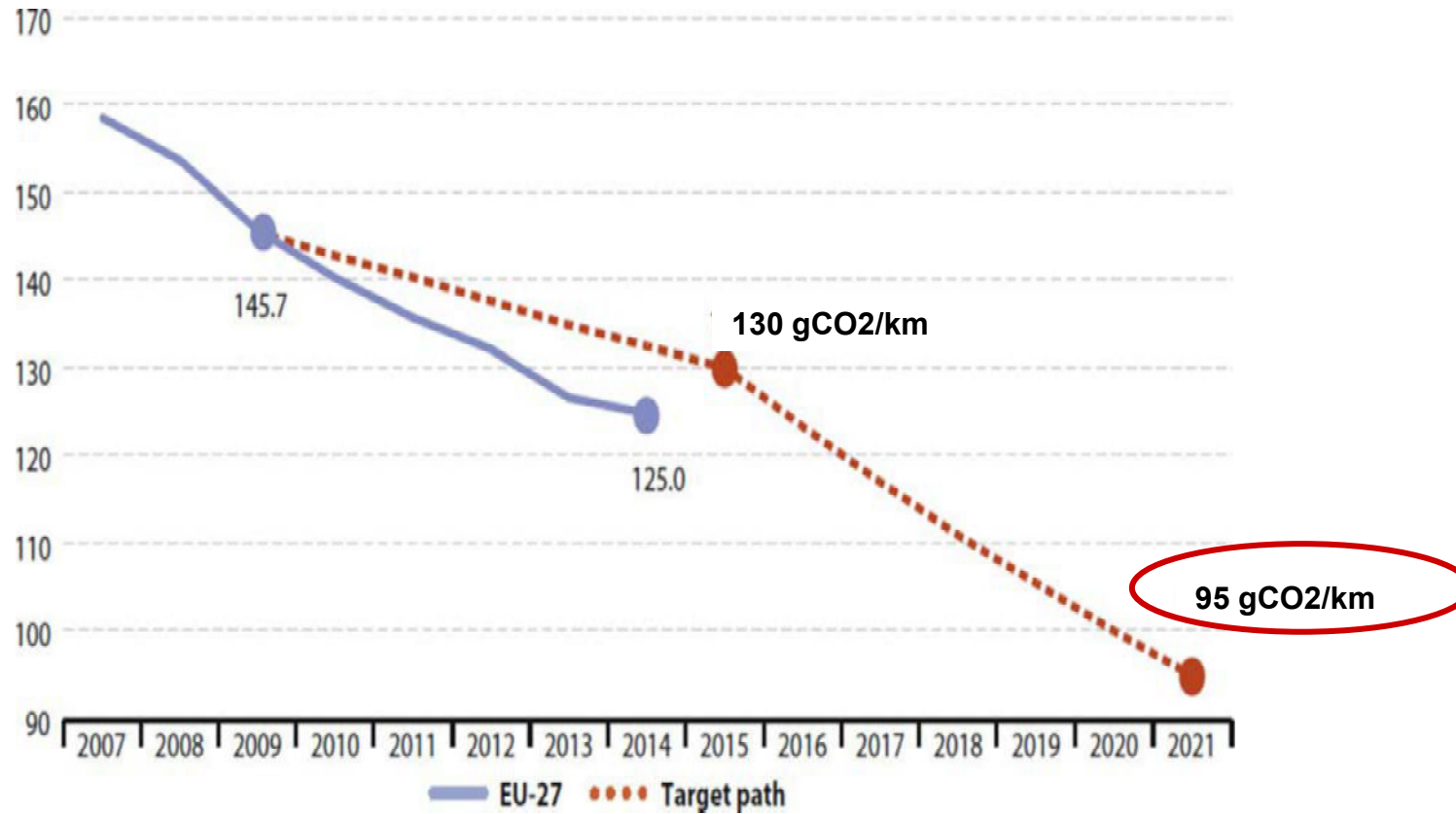
Effective policies and measures

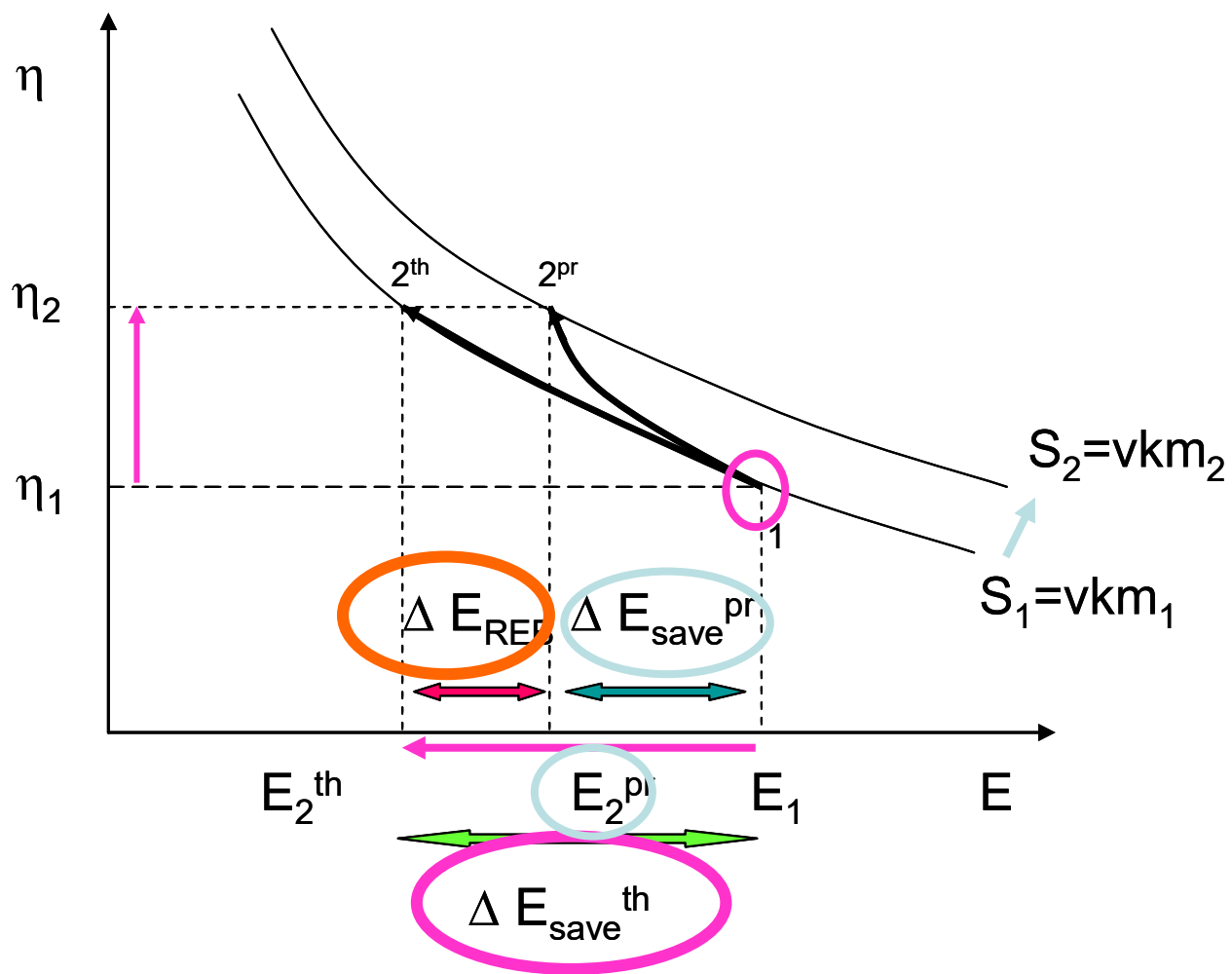The challenges for EU climate and energy policies

Energy policy

Impact factors on CO_2 emissions in the car passenger transport sector
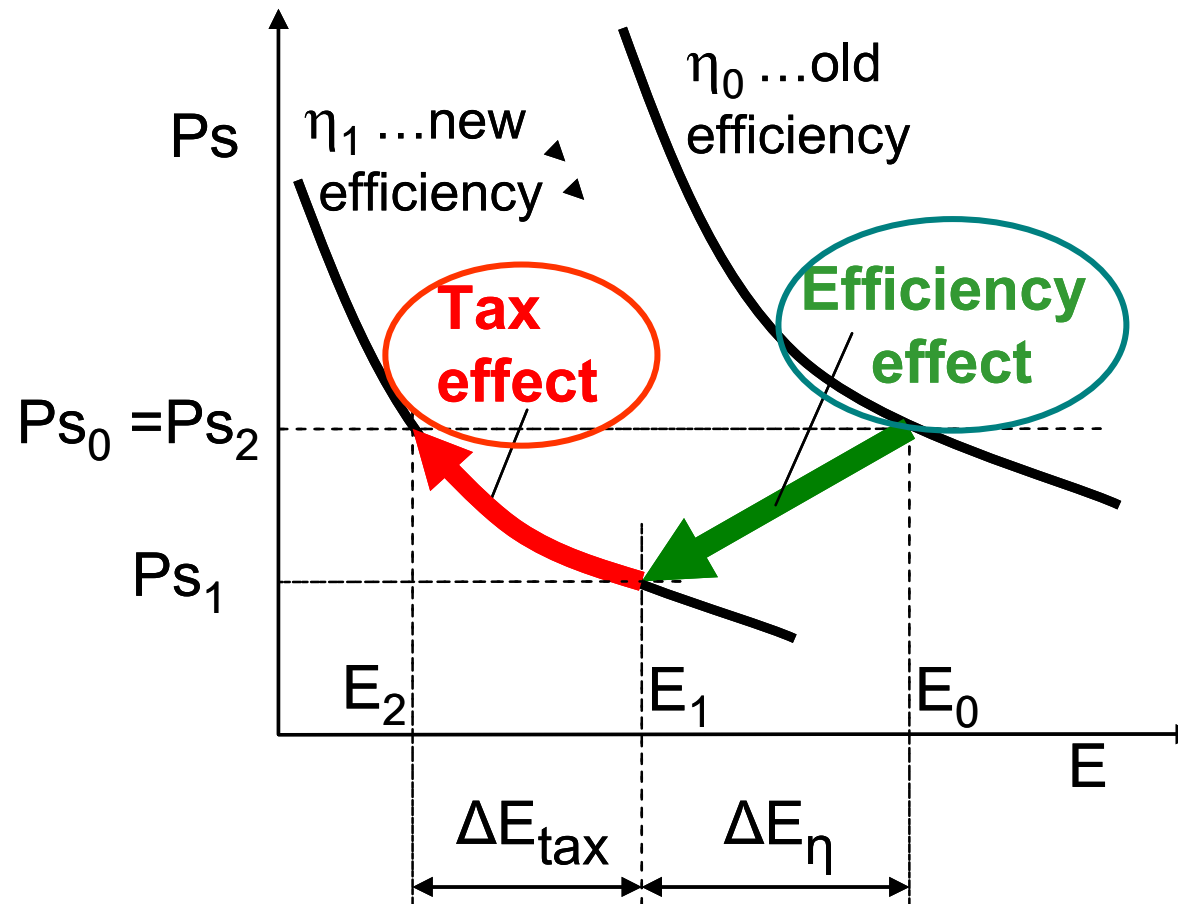
Energy Policy

Targets and average CO_2 emissions from new passenger cars in EU countries
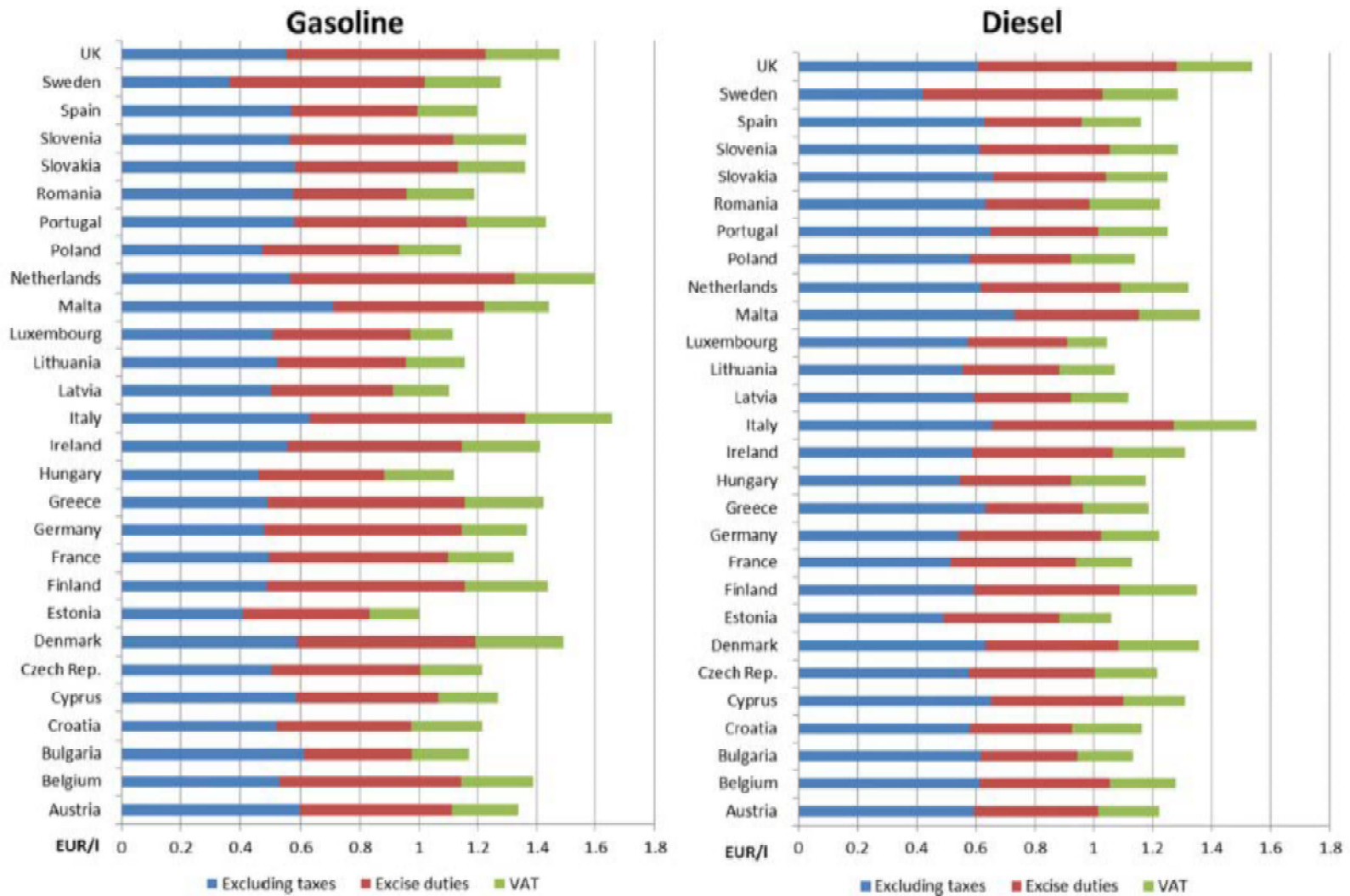
Rebound-effect

The rebound effect

Standards & taxes

How taxes and standards interact and how they can be implemented in a combined optimal way for society

Price structure of gasoline and diesel

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

Registration and ownership taxes

| Registration tax based on:	
CO$_2$ emissions	Austria, Cyprus, Spain, France, Ireland, Lithuania, Malta
Car price+CO$_2$ emissions	Finland, Hungary, Croatia, Netherlands, Slovenia
Cylinder capacity	Belgium, Greece, Hungary, Poland, Portugal, Romania
Kilowatt/weight/seats	Italy, Slovakia
None	Bulgaria, Czech Republic, Germany, Estonia, Luxembourg, Sweden, United Kingdom

| Ownership tax based on:	
Fuel consumption	Denmark
Weight	Lithuania, Denmark, Sweden
CO$_2$ emissions	Cyprus, Germany, Italy, Croatia, Ireland, Luxemburg, Sweden, United Kingdom
Power (horsepower; kilowatt)	Spain; Austria, Bulgaria, Italy, Hungary
Cylinder capacity	Belgium, Malta, Romania, Slovenia, United Kingdom
None	Czech Republic, Estonia, France, Lithuania, Poland, Slovakia

6. *Future scenarios and perspectives*

Scenarios

A scenario is a plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions ("scenario logic") about key relationships and driving forces (e.g., rate of technology changes, prices). Note that scenarios are neither predictions nor forecasts. (SRES, 2000)
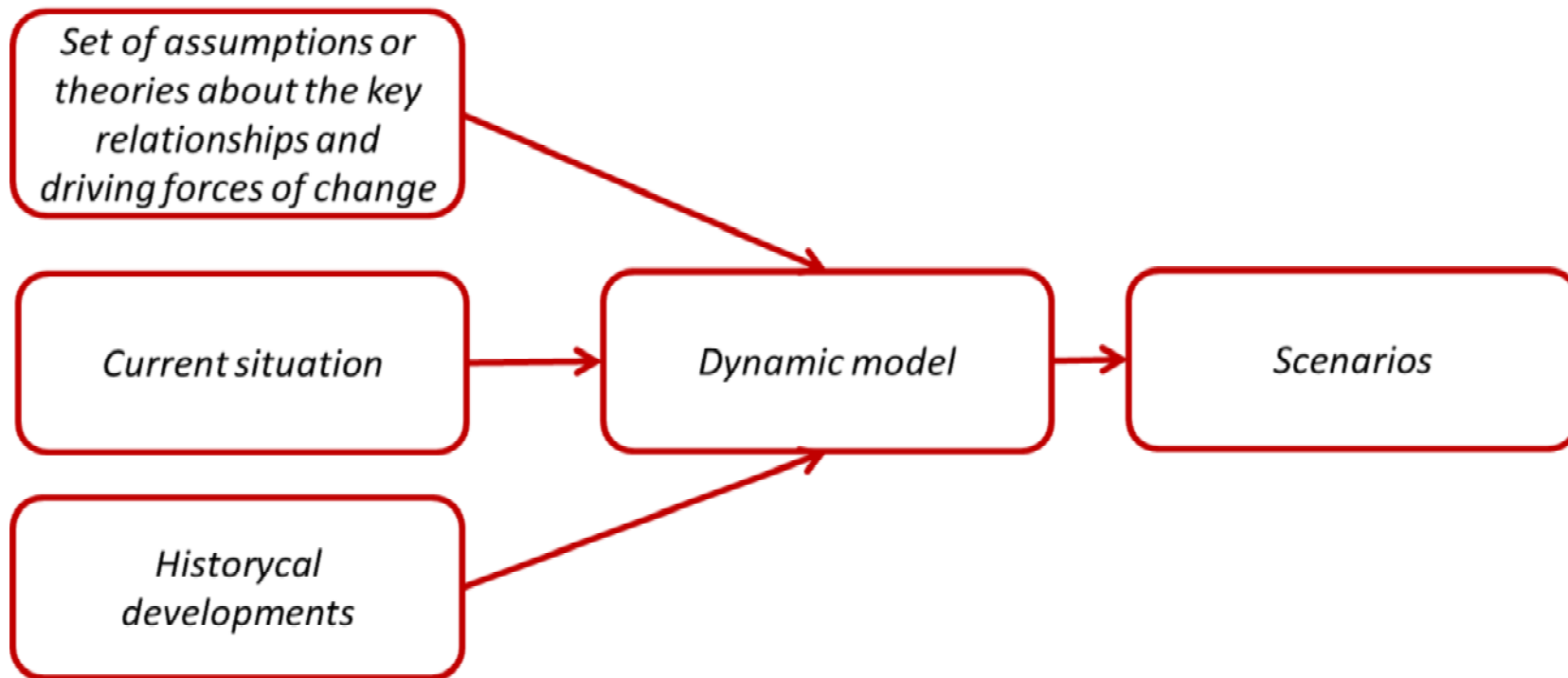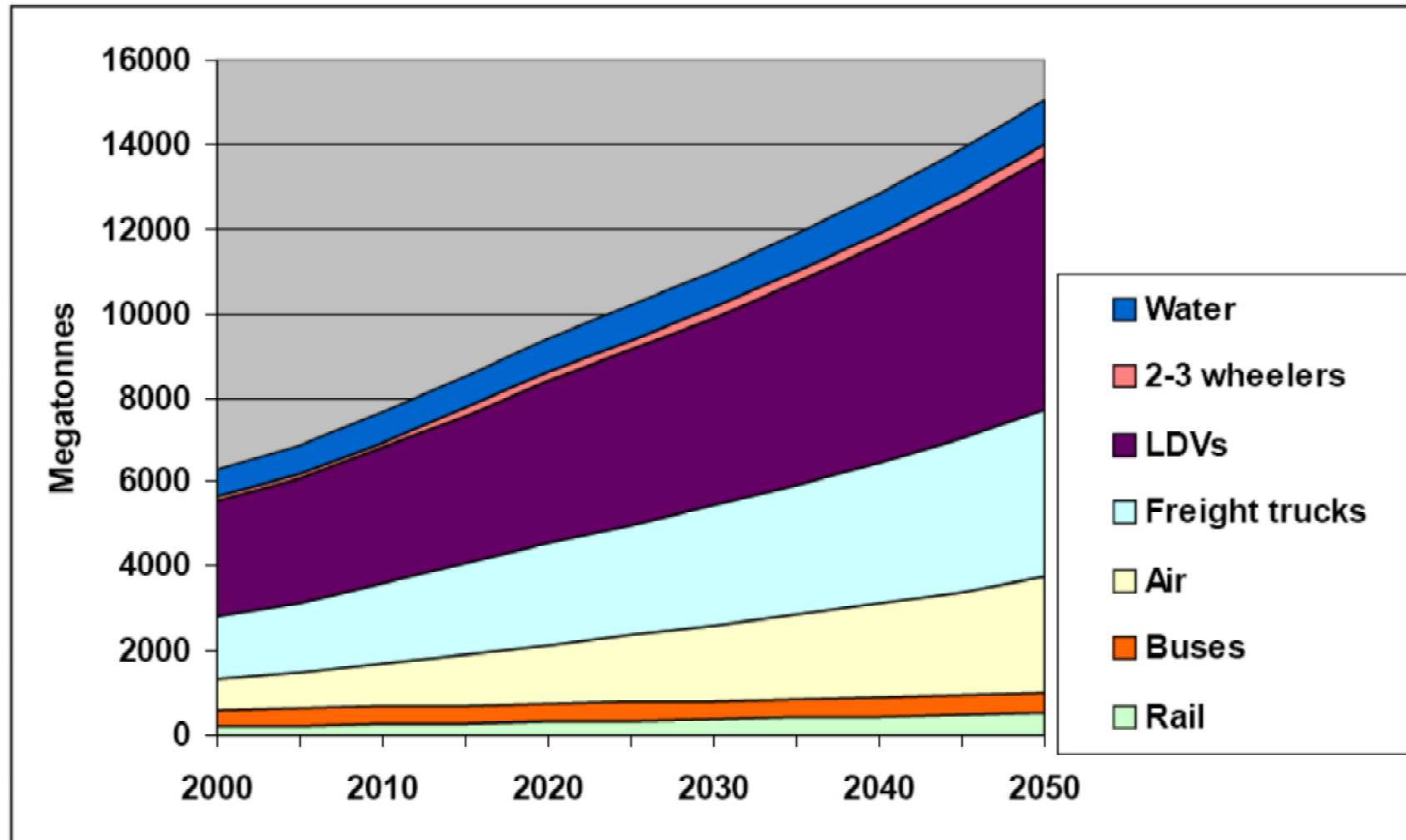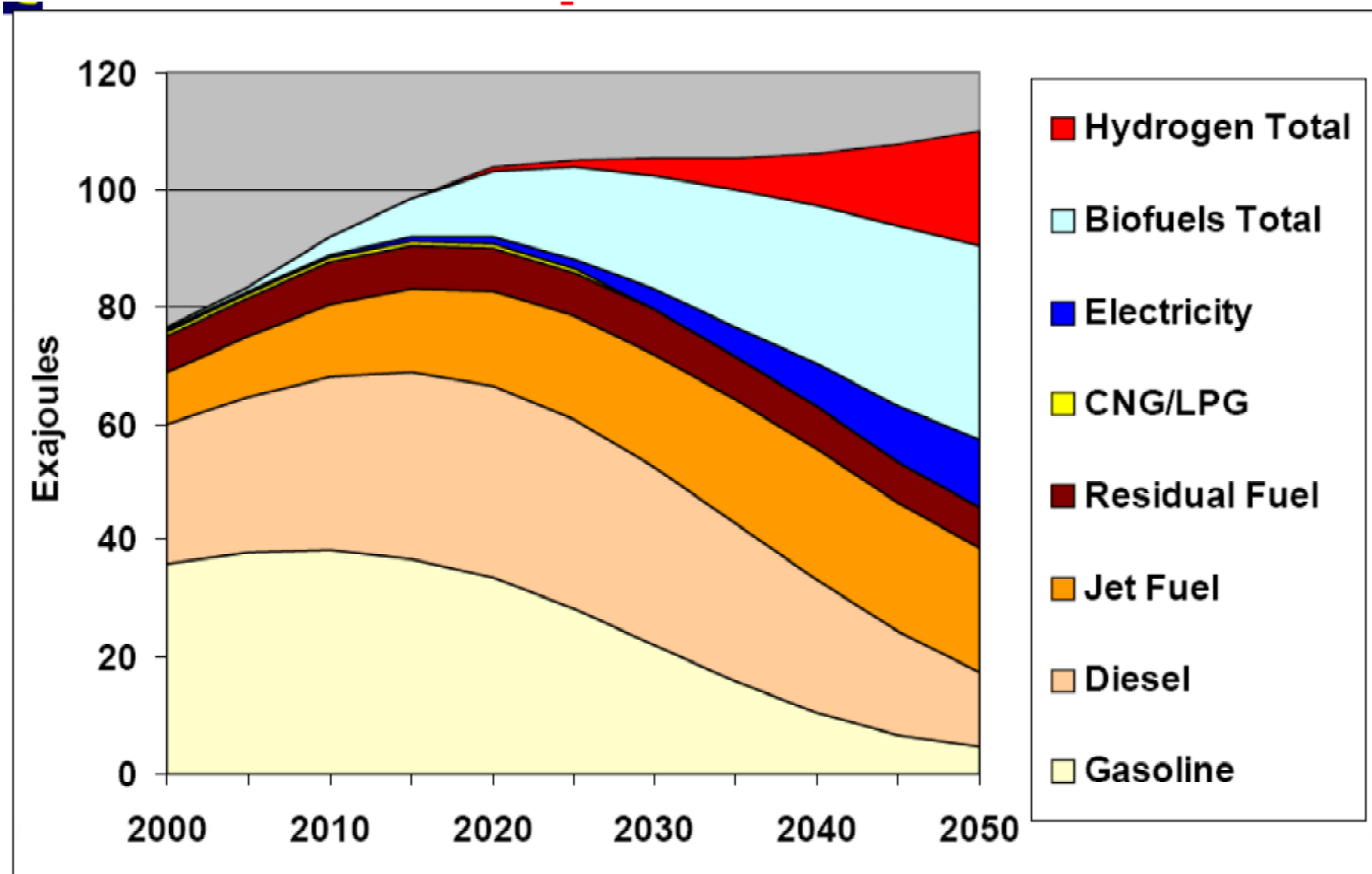
Ref. Case: Fuel Use
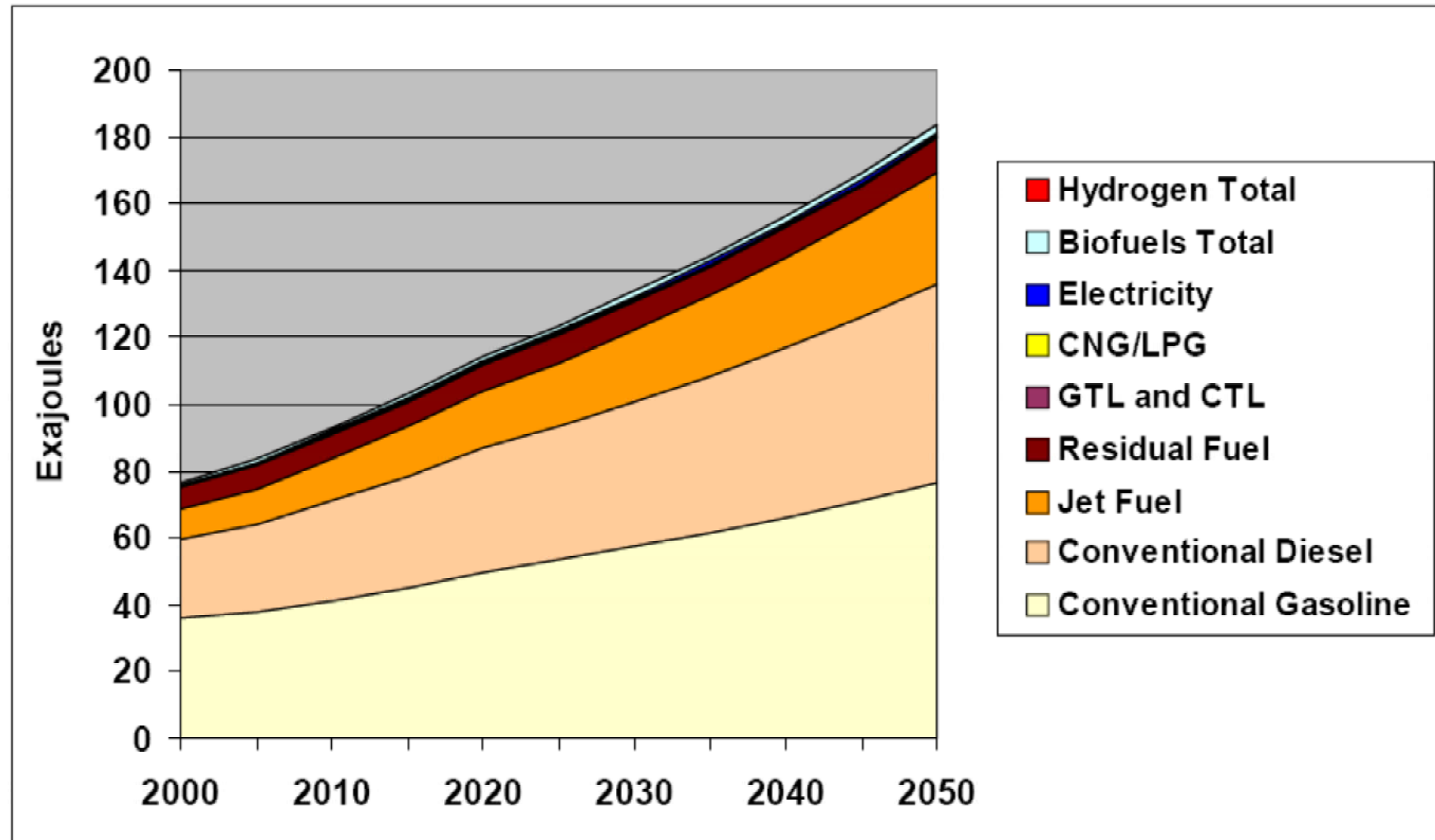
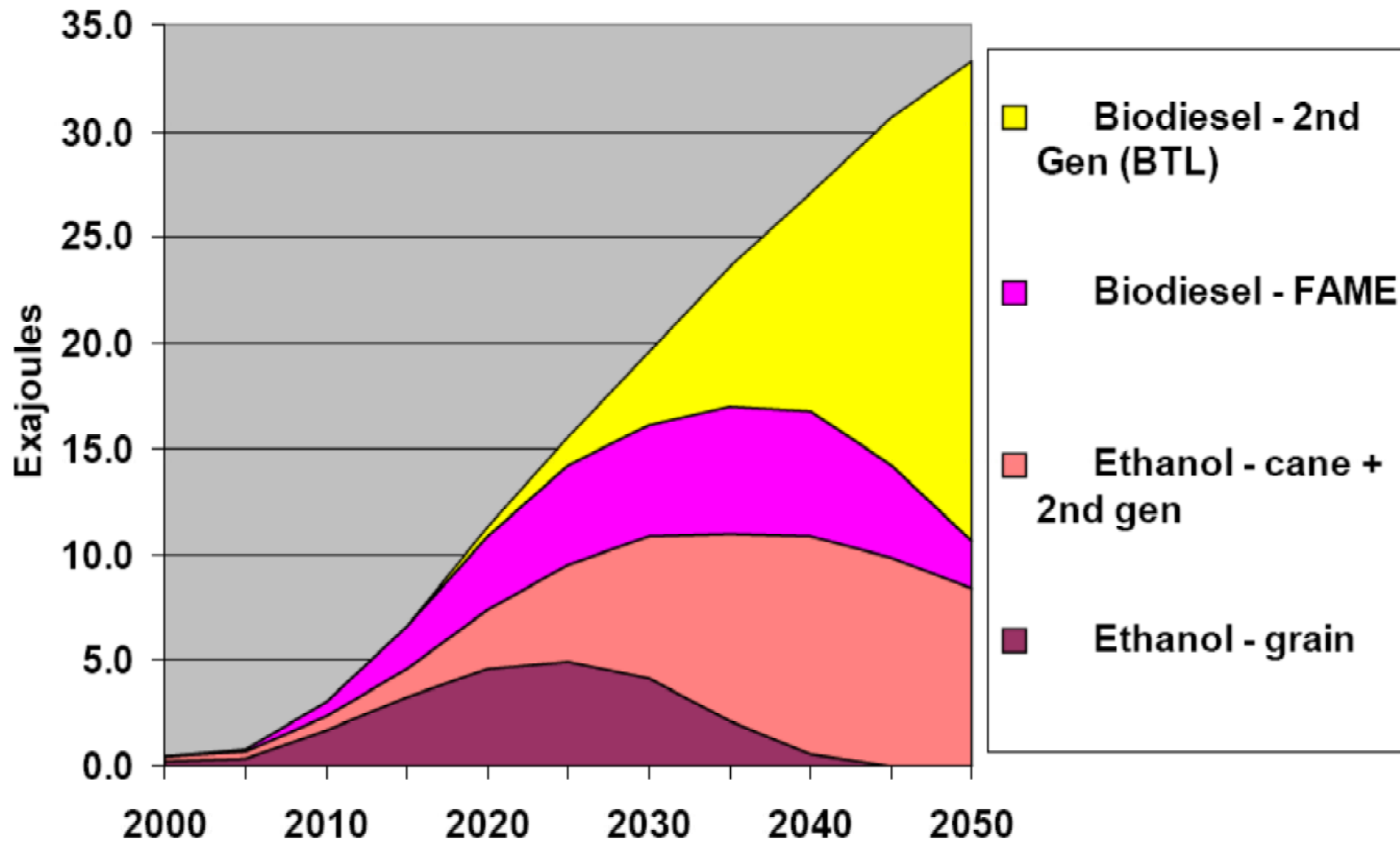

Souce: IEA, 2007

Ref. Case: Emissions by Mode (WTW)

Souce: IEA, 2007

Alternative Scenario (AS): Transport Fuel Use
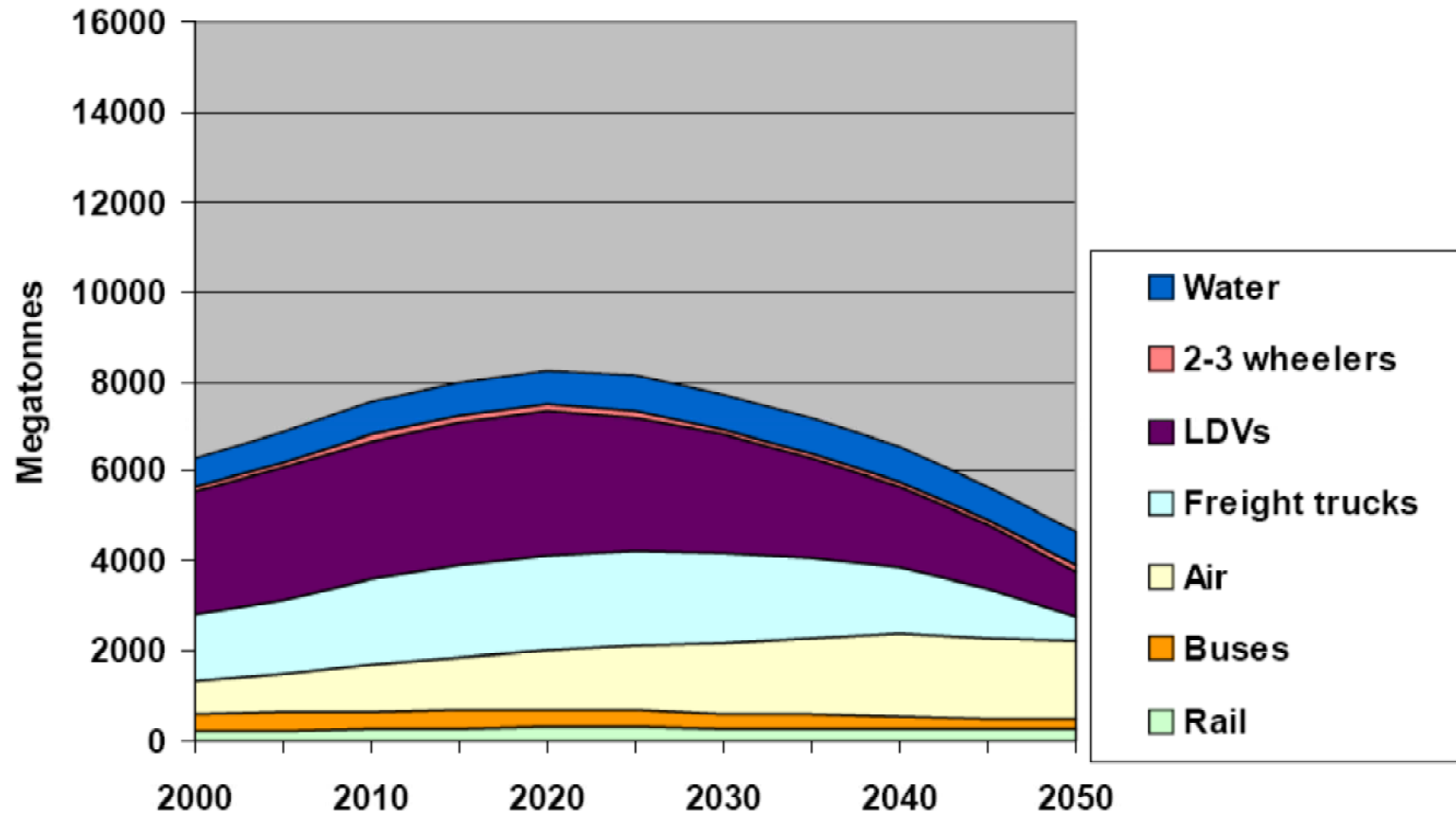

Souce: IEA, 2007

AS: Biofuels Breakdown

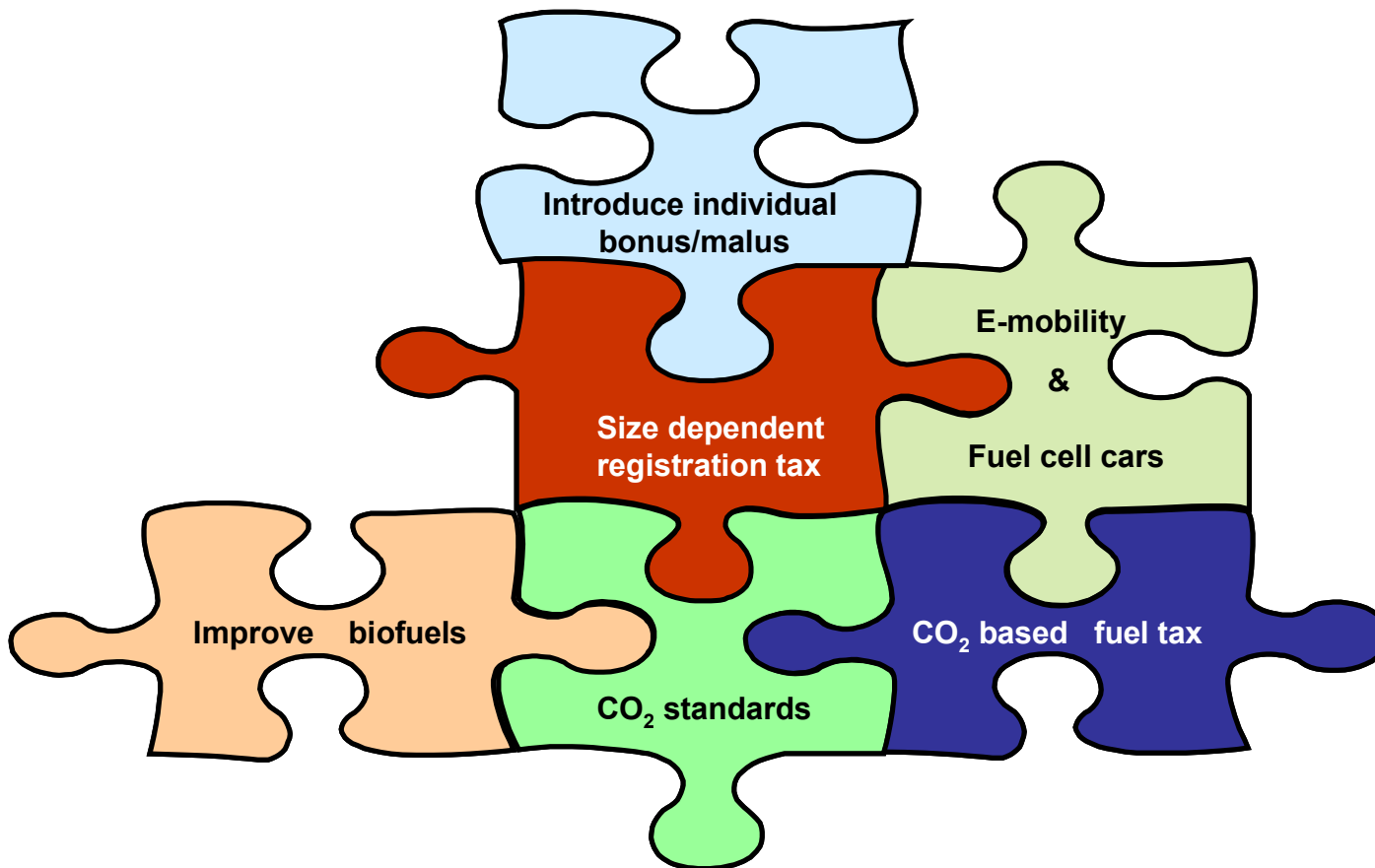# AS: GHG Emissions by Sector

Conclusions

ajanovic@eeg.tuwien.ac.at