The Role of Hydrogen in the Development of Sustainable Mobility

Amela Ajanovic
Energy Economics Group
TU WIEN

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- ✓ Economic and environmental assessment
- ✓ RES and storage
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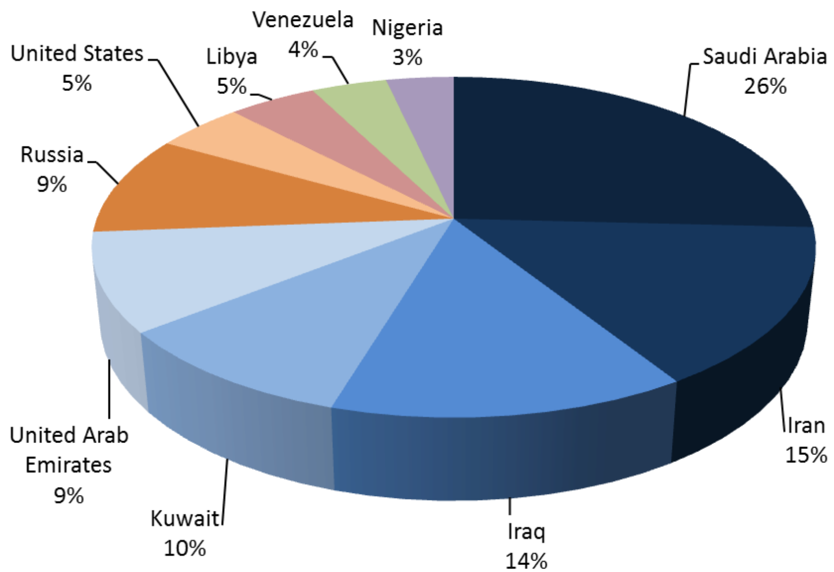
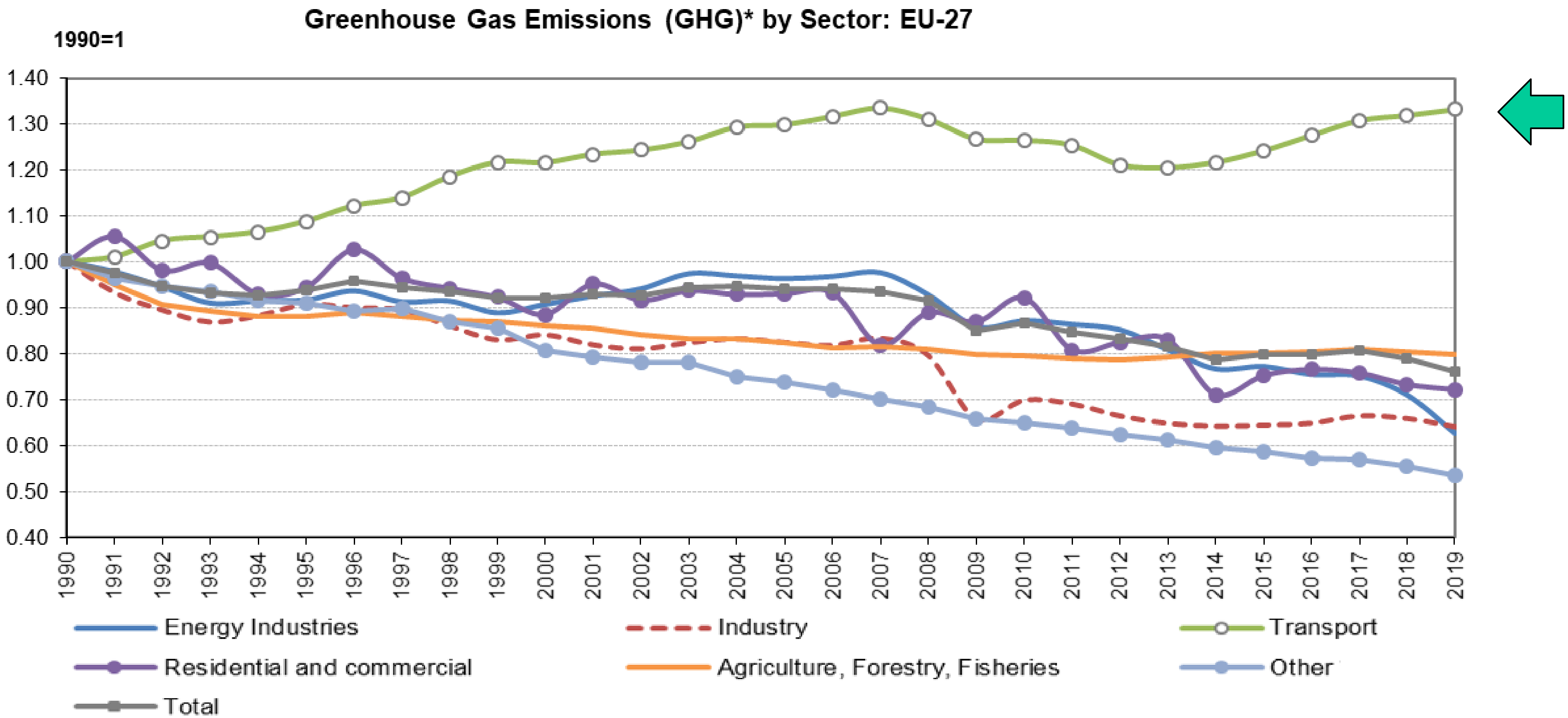
Transport sector

- oil products
- least-diversified
- energy import dependency

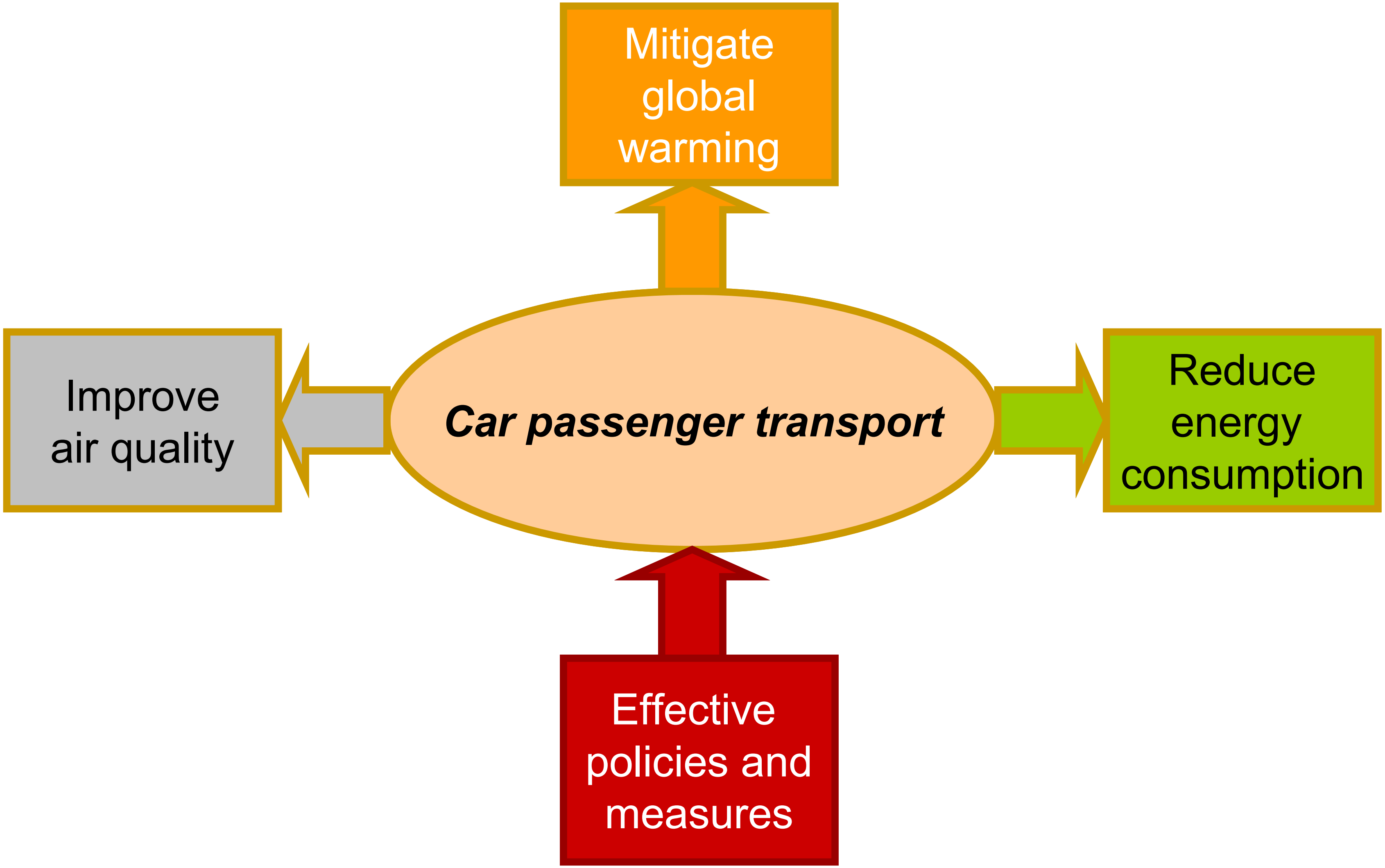


Countries with largest conventional oil reserves

GHG


Greenhouse Gas Emissions (GHG)* by Sector: EU-27
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
2018
2019
Energy Industries
Industry
Transport
Residential and commercial
Agriculture, Forestry, Fisheries
Other
Total

The challenges for EU climate and energy policies



EU targets

EU - the first climate-neutral continent by 2050

European Green Deal

2030 climate & energy framework

40-32-32,5

14%

Sustainable and Smart Mobility Strategy

at least 30 million zero-emission cars will be in operation on European roads

nearly all cars, vans, buses as well as new heavy-duty vehicles will be zero-emission.

2009 2010 2015 2020 2025 2030 2050

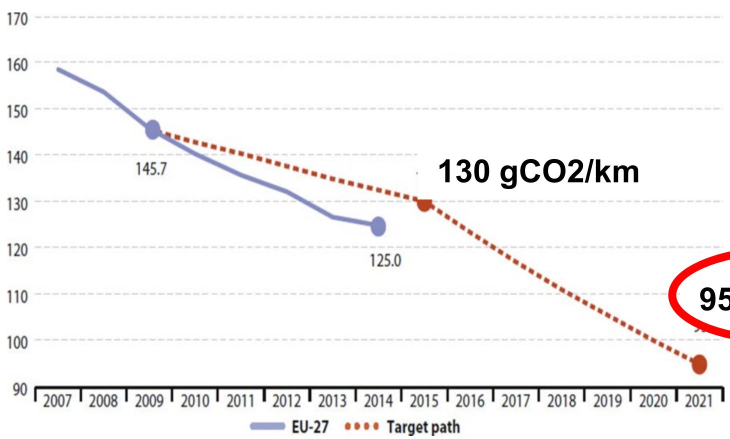
ICE -50% in city

20% GHG (2008)

No ICE in city

60% GHG (1990)

Transport White Paper



130 gCO2/km

95 gCO2/km

-15%

-37,5%

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

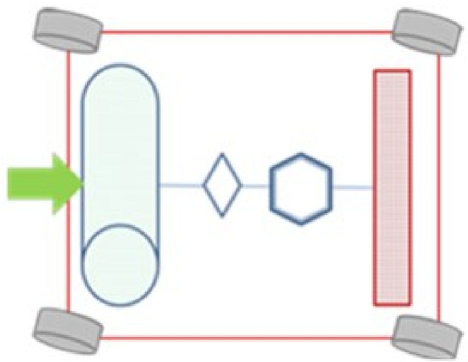
Announced 100% ZEV sales targets and bans on ICE vehicle sales

	2025	2030	2035	2040	2045	2050
Costa Rica						● (green)
Denmark		● (green)				
France				● (green)		
Iceland		● (green)				
Ireland		● (green)				
Israel*		● (green)		● (blue)		
Netherlands		● (green)			● (blue)	
Norway	● (green)					
Portugal				● (green)		
Slovenia		● (green)				
Spain				● (green)		● (blue)
Sri Lanka				● (blue)		
United Kingdom				● (green)		

● (green) ICE sales ban or 100% ZEV sales target

● (blue) Fleet without ICEs

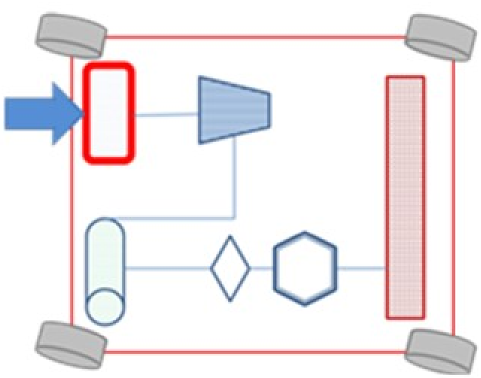
Zero-emission vehicles



BEV

~ 11 000 000

~ 42 400



FCV

ZEV

100% electrification

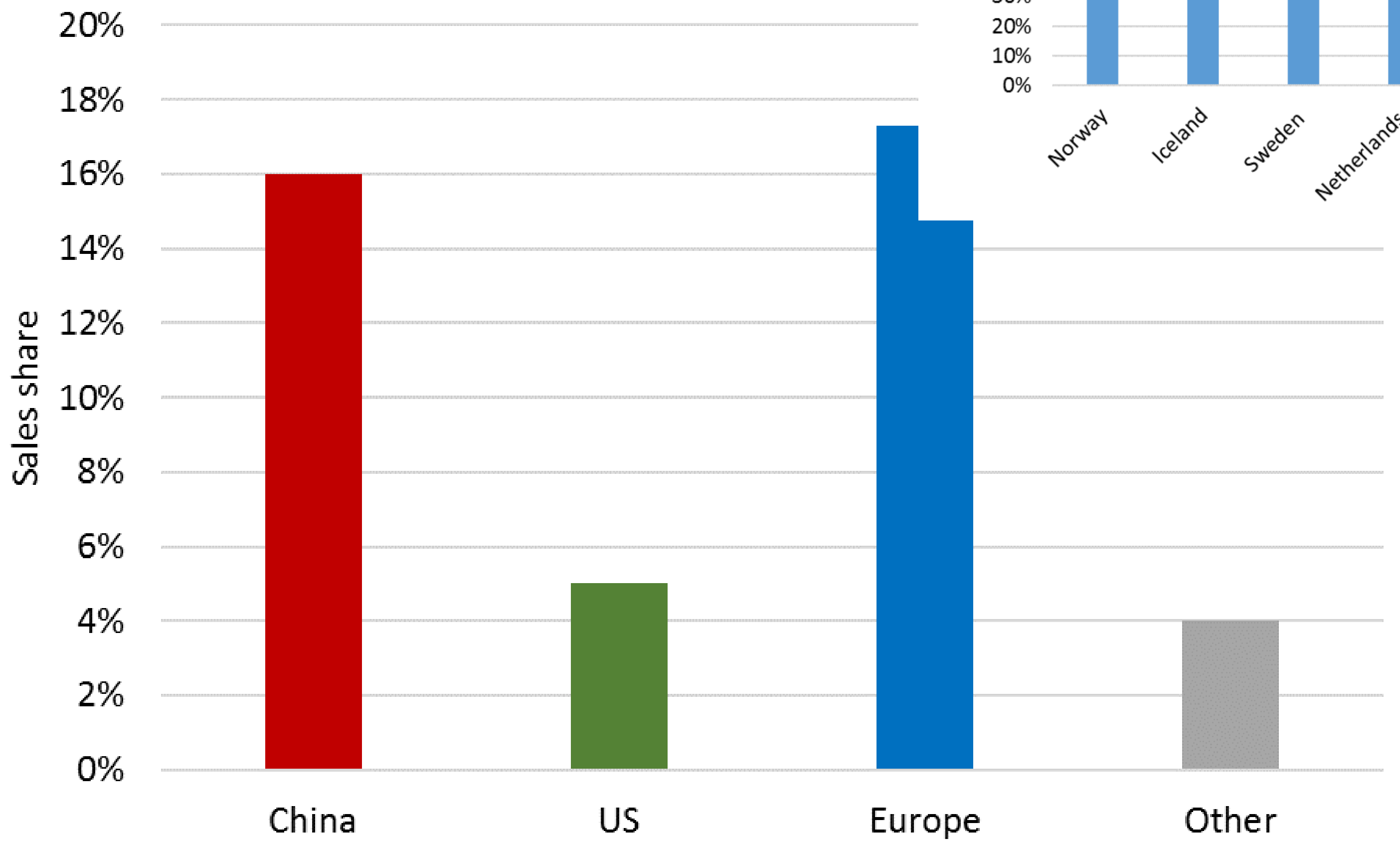
Advantages

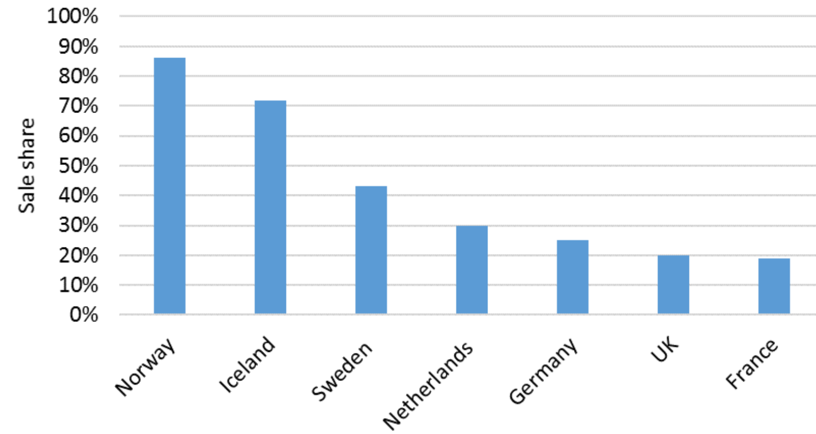
- ✓ Energy efficiency
- ✓ Energy security
- ✓ Air pollution
- ✓ Noise reduction
- ✓ GHG emissions

Disadvantages

- – Costs
- – Infrastructure

Electric car sales, 2021





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GDP and EV sales

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73% of all electric cars are sold in just 4 countries (with some of the highest GDPs)

Electric cars < 3% of total sales
= average GDP < €17,000

Electric cars > 15% of total sales
= average GDP > €46,000

Top 5: Lowest market share in 2020

Cyprus	Lithuania	Estonia	Croatia	Poland
0.47%	1.13%	1.82%	1.86%	1.89%
42 ECVs	453 ECVs	425 ECVs	676 ECVs	8,099 ECVs
GDP €23,580	GDP €17,460	GDP €20,440	GDP €12,130	GDP €13,600

ACEA

GDP and charging infrastructure

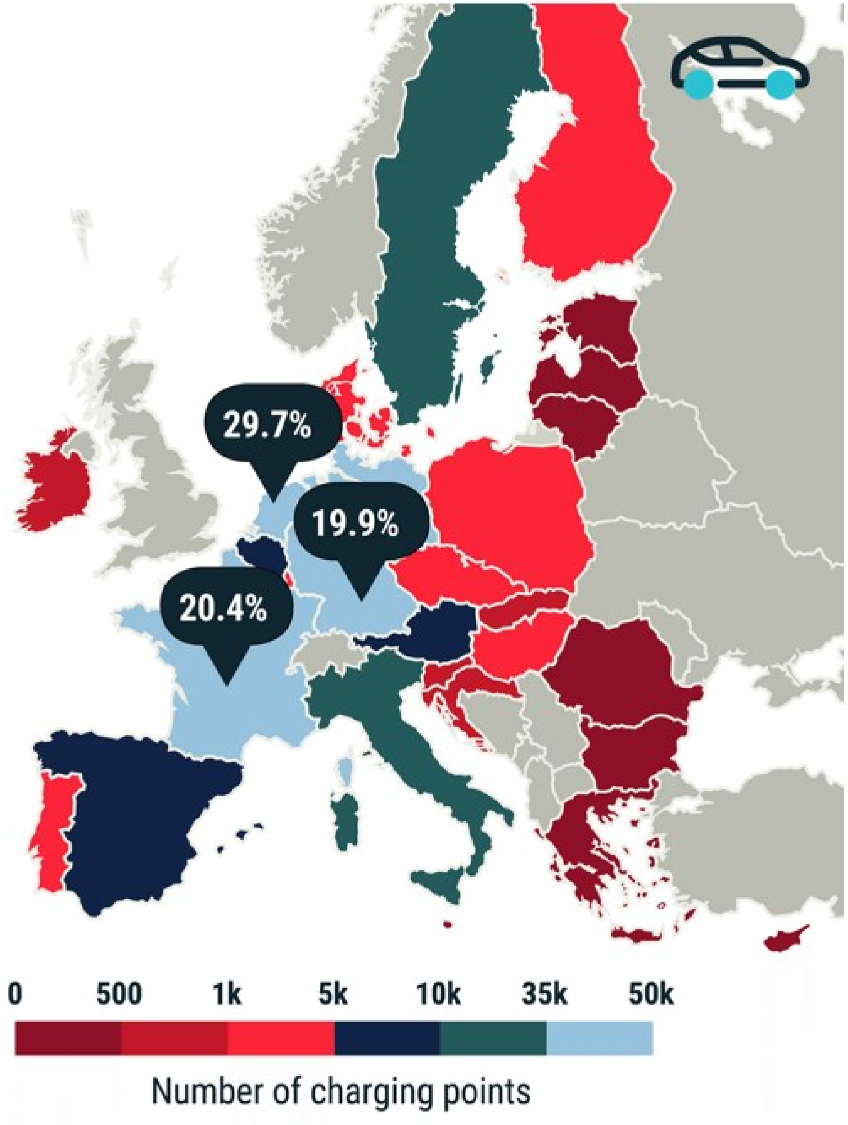
70% of all charging points:

Located in just 3 EU countries

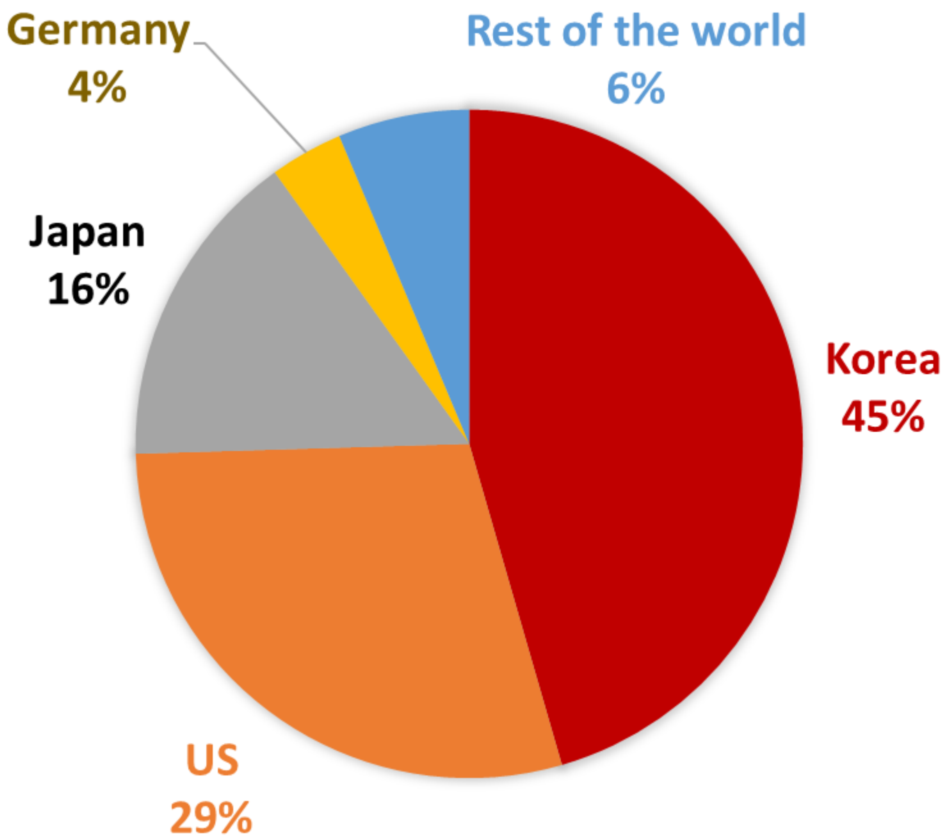
29.7% **Netherlands**

20.4% **France**

19.9% **Germany**



FCV

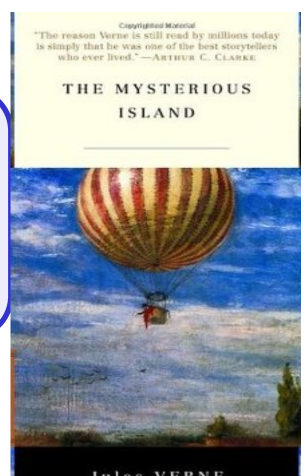


Major historical steps and milestones in the development of hydrogen and FCV

1766: Hydrogen was first identified as a distinct element

1838: Discovered fuel cell effect

1874: Vision of hydrogen economy



1958: The first PEM fuel cell

1959: The first fuel cell vehicle – farm tractor powered by an alkaline fuel cell

1966: General Motors used fuel cell technology in production of the Electrovan

1993: The first PEMFC car

2008: Commercialization begins (FCX Clarity – first FCV commercially available)

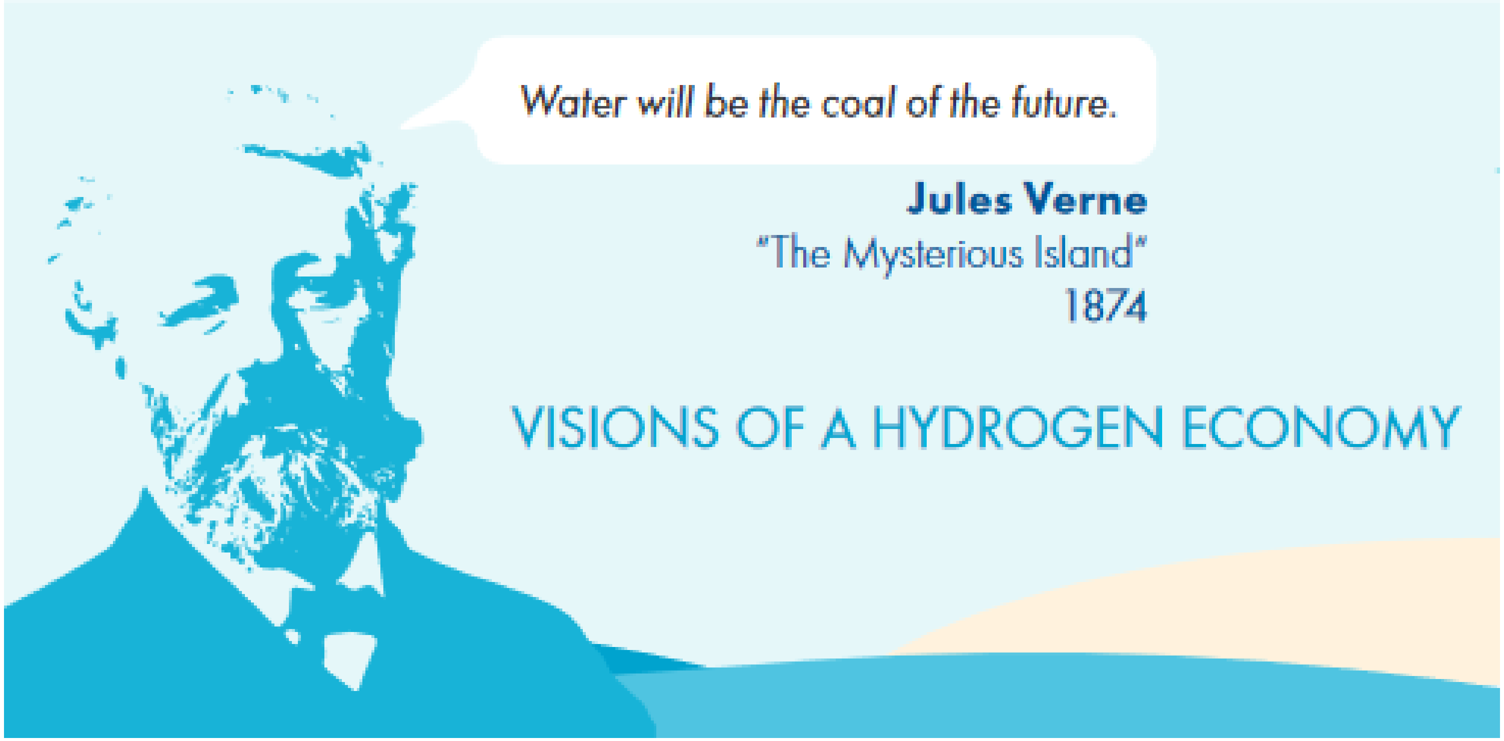
2011: > 100 fuel cell buses worldwide

2013: > 4000 fuel cell forklifts worldwide

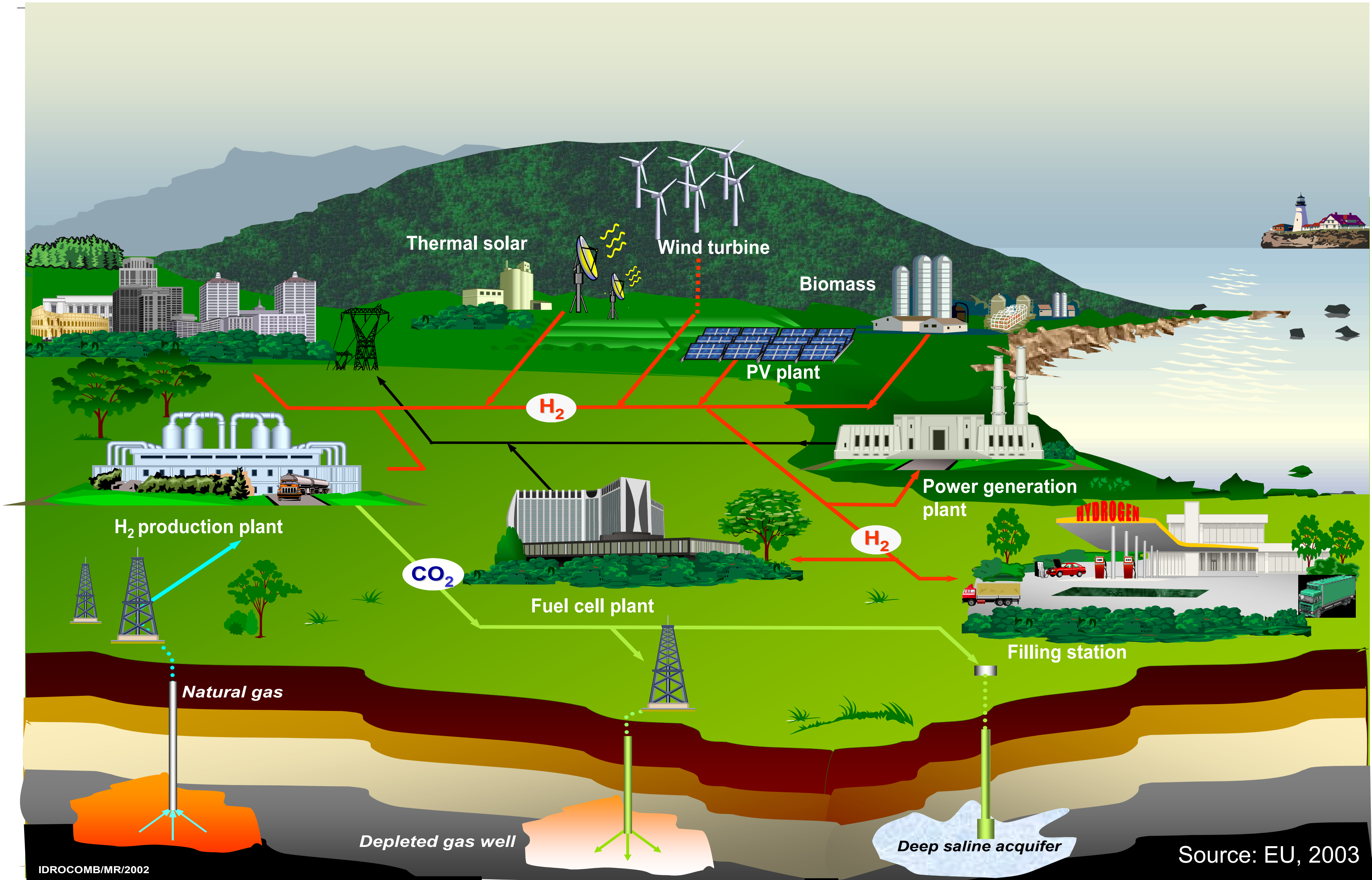
2015: First hydrogen fuel cell powered tramcar

2021: The global FCV stock >40 000

Visions of a hydrogen economy



Hydrogen vision



Source: EU, 2003

EU hydrogen strategy

A hydrogen strategy for a climate-neutral Europe (2020)

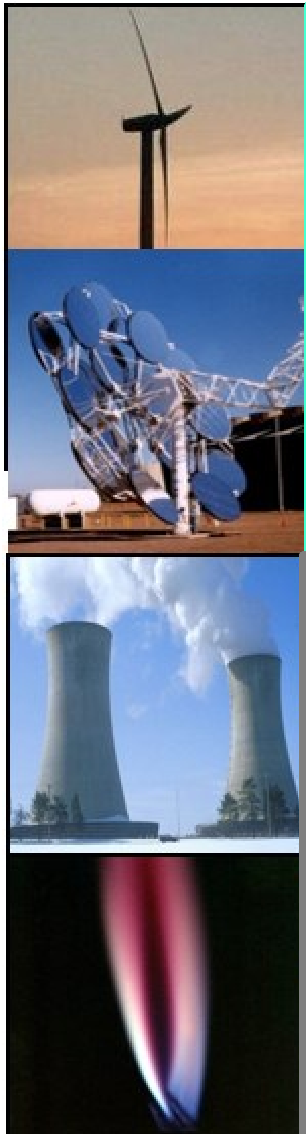
Renewable and low-carbon hydrogen can contribute:

- ✓ to reduce greenhouse gas emissions
- ✓ to the recovery of the EU economy
- ✓ to the realization of a climate-neutral and zero pollution economy in 2050

Hydrogen

- Hydrogen is the simplest, lightest and most abundant element in the universe
- high energy density
- less flammable than gasoline
- non-toxic
- hydrogen combustion produces only water
- secondary energy carrier …. It can be produced from different energy sources

Colors of hydrogen



Biomass
Hydro
Wind
Solar

→ Green H2

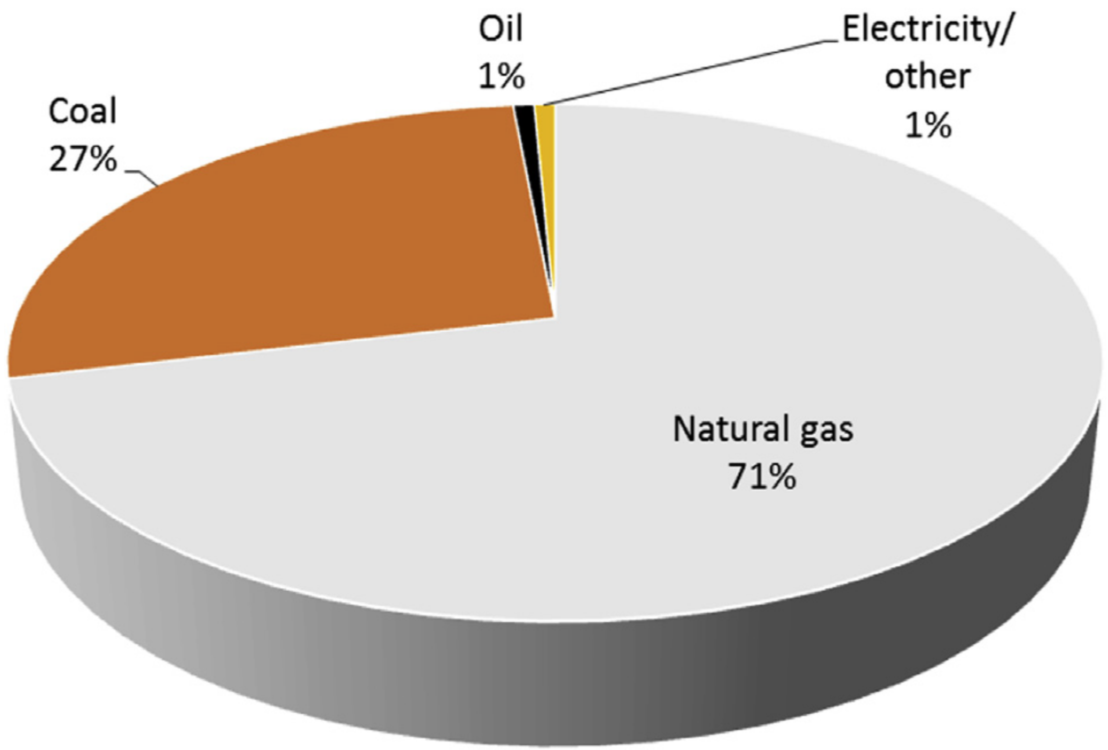
Oil
Coal
Natural gas

→ Grey H2

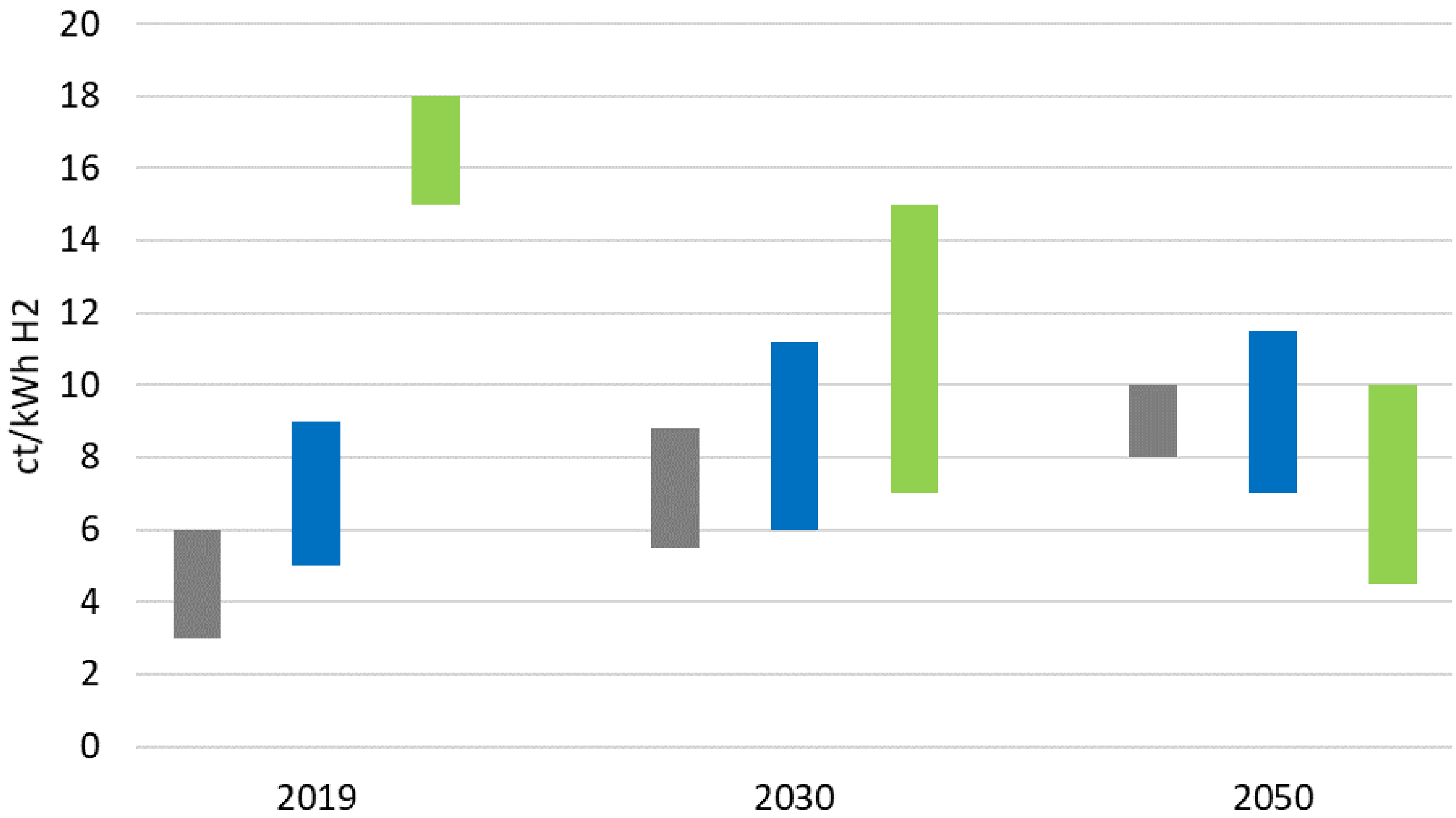
With Carbon Sequestration

→ Blue H2

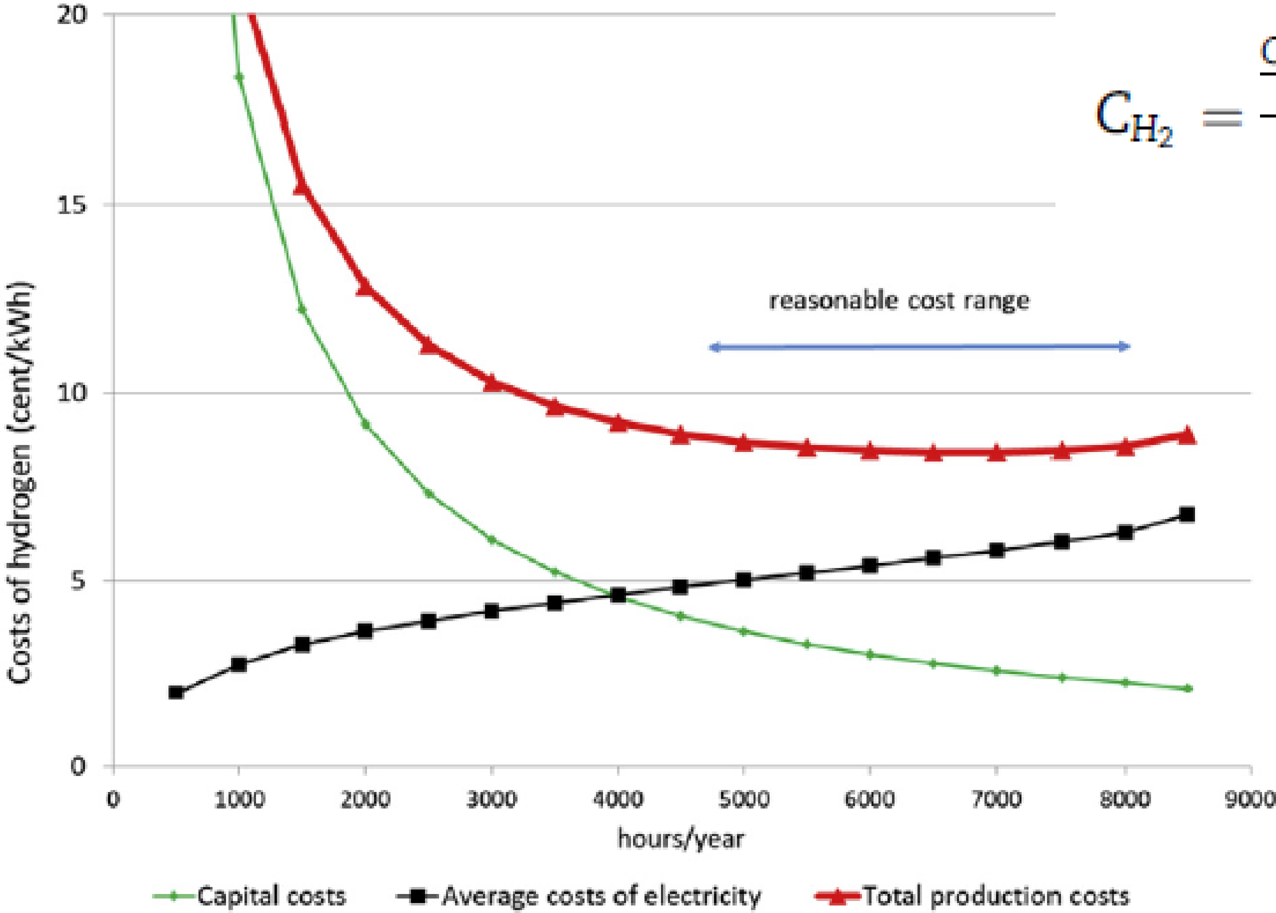
Hydrogen production



H2 production costs



Electrolysis



$$C_{H_2} = \frac{\frac{C_c + C_{O\&M}}{T} + C_E}{\eta}$$

Economic assessment

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

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

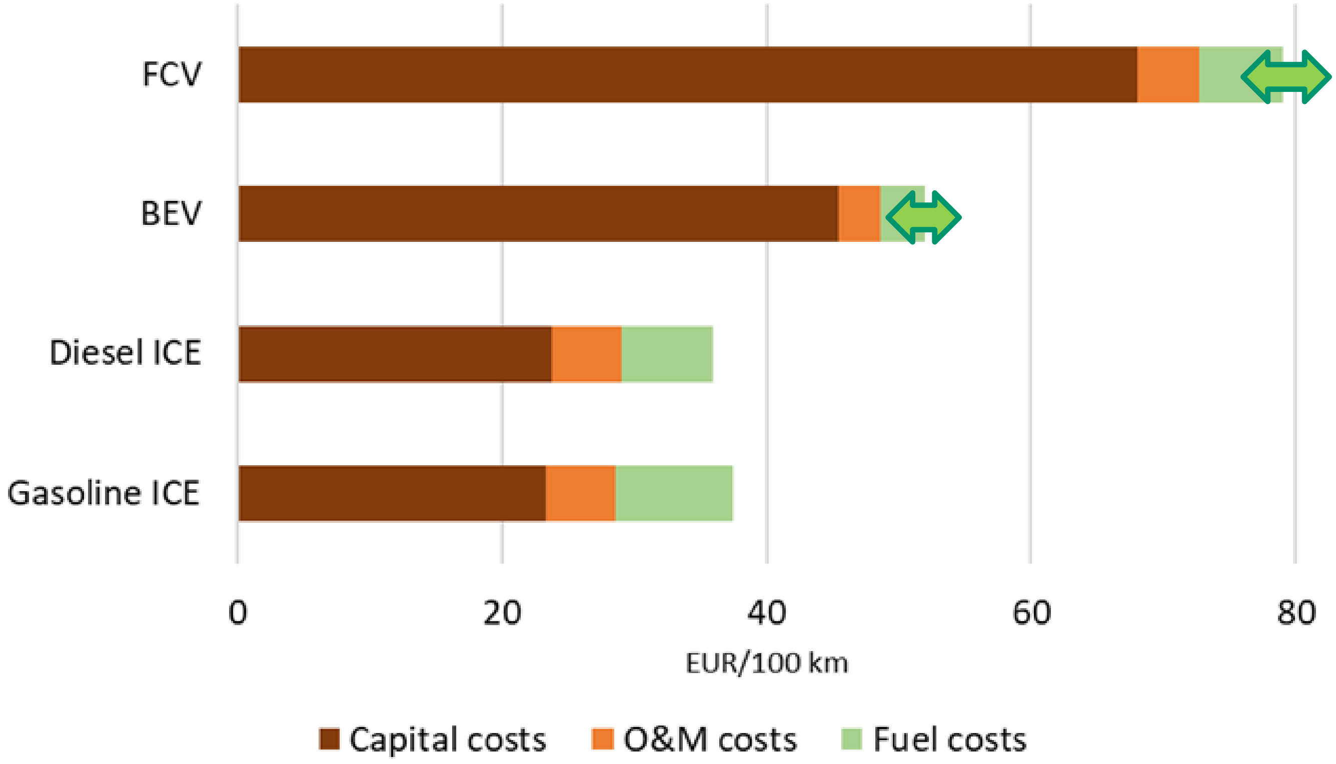
IC……investment costs [€/car]
α……..capital recovery factor
skm…..specific km driven per car per year [km/(car.yr)]
Pf……..fuel price incl. taxes [€/litre]
$C_{O\&M}$…operating and maintenance costs
FI……..fuel/energy intensity [litre/100 km; kWh/100 km]

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:

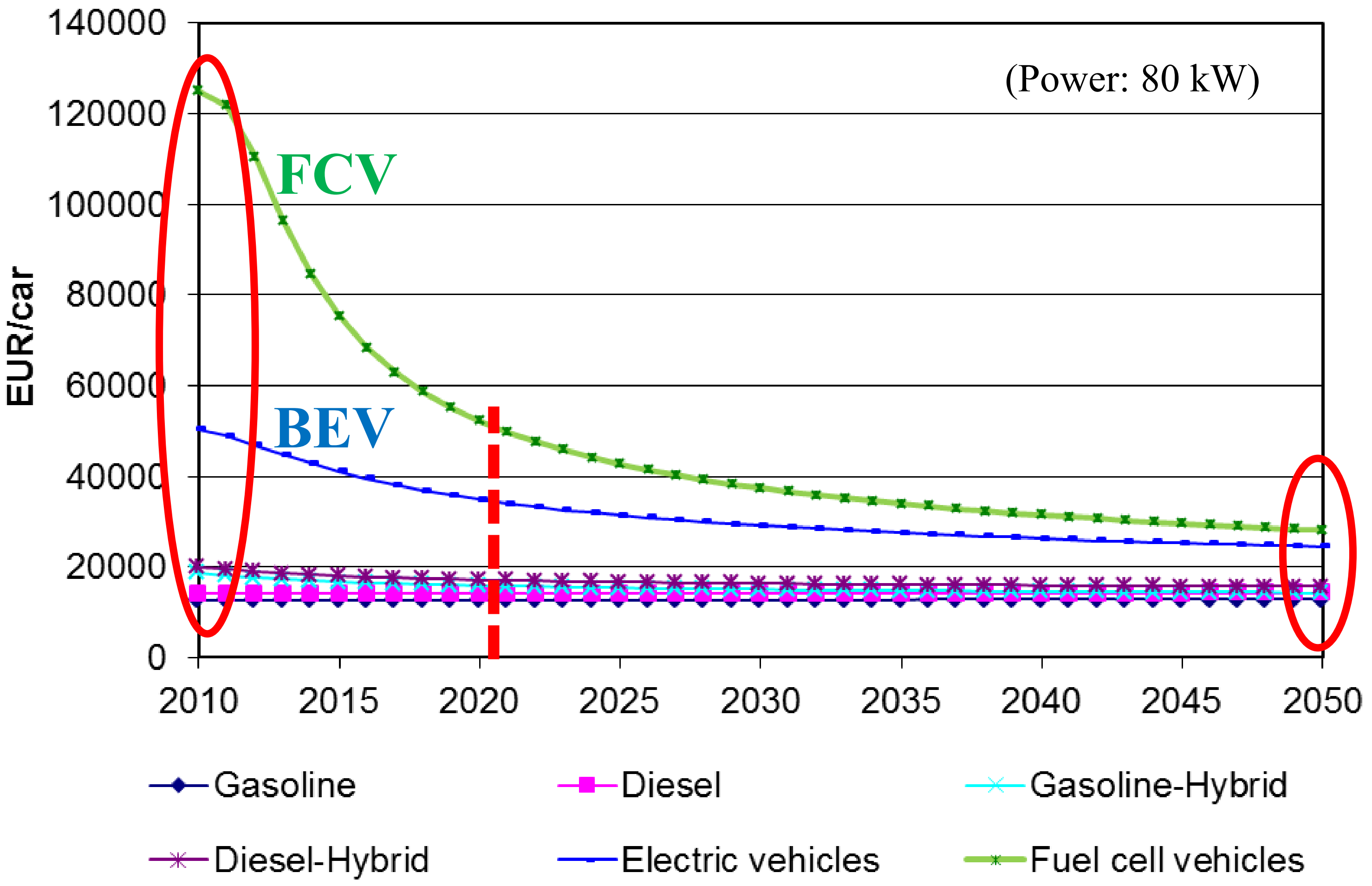
$$\alpha = \frac{z(1+z)^n}{(1+z)^n - 1}$$

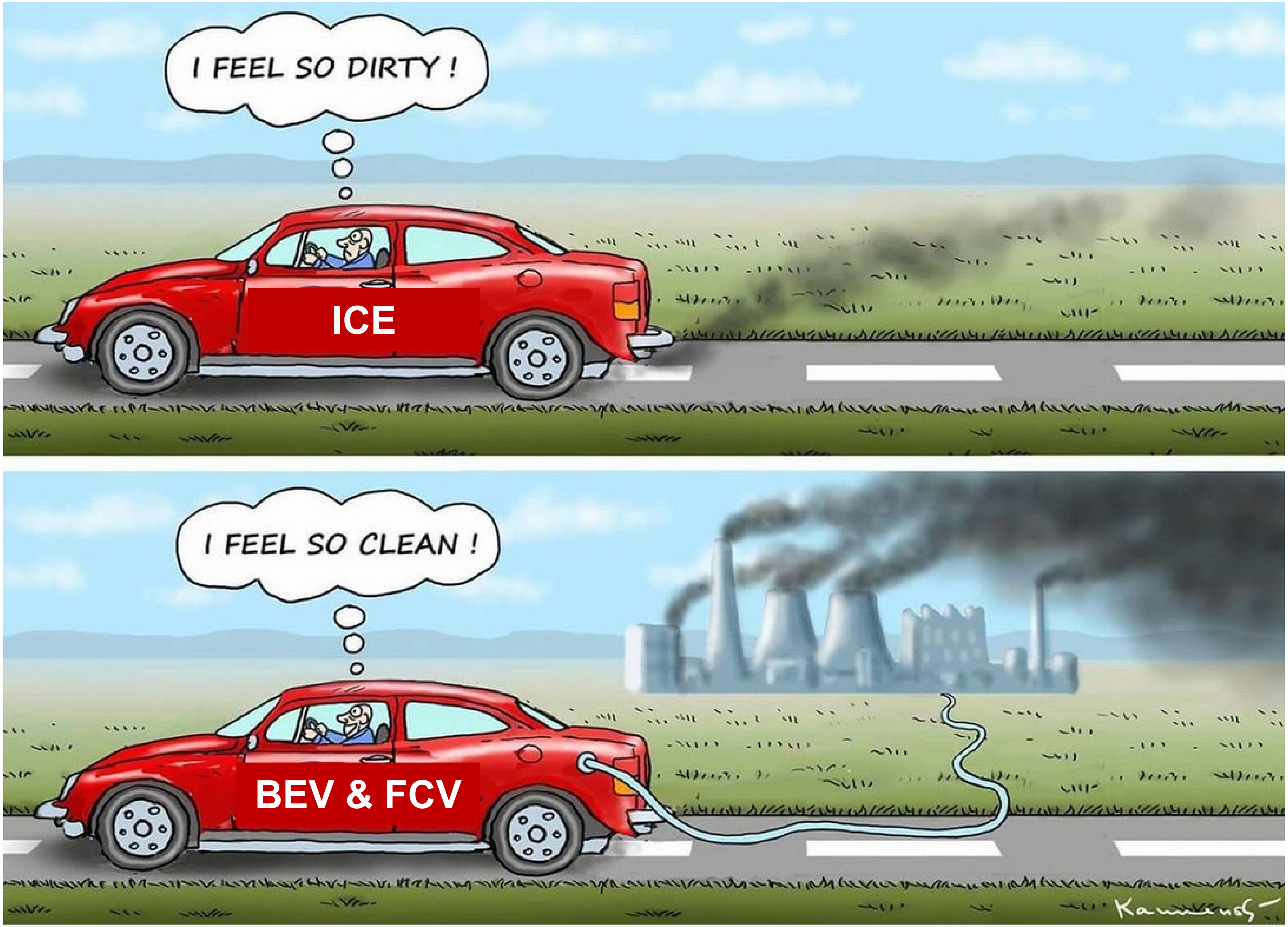
n…..the number of annuities received.

Mobility costs



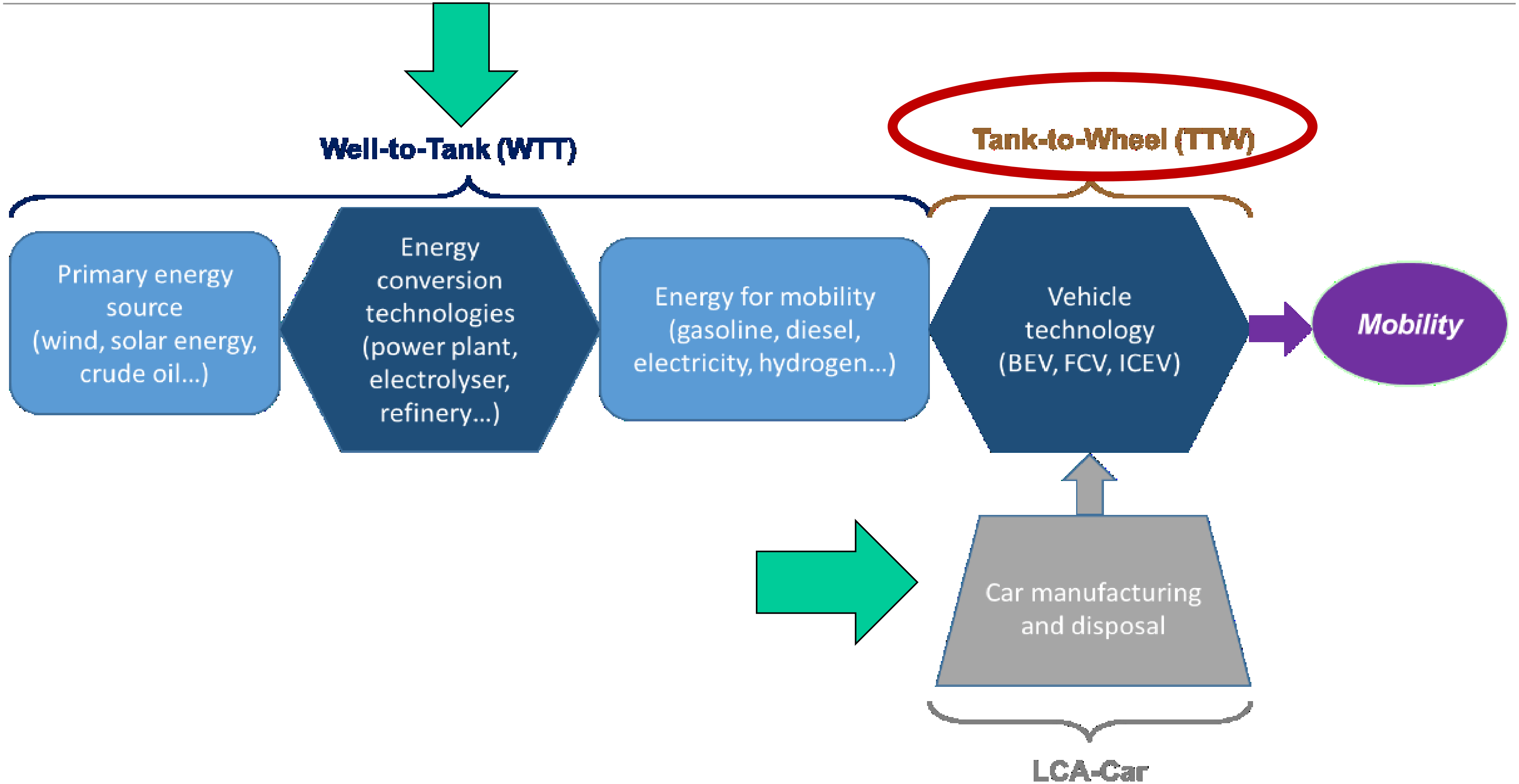
Scenario for development of investment costs



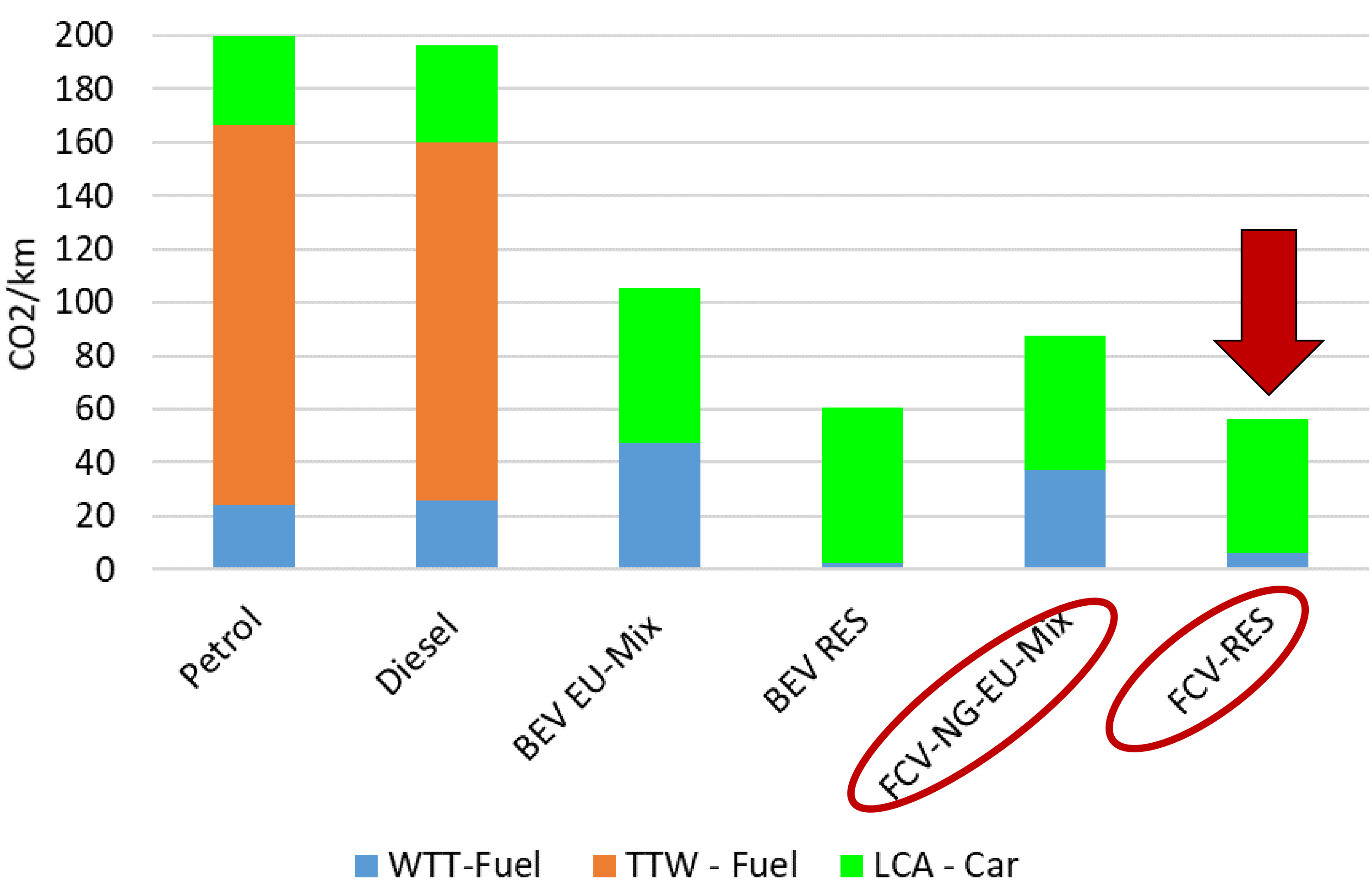


Artist: Marian Kamensky

Environmental assessment

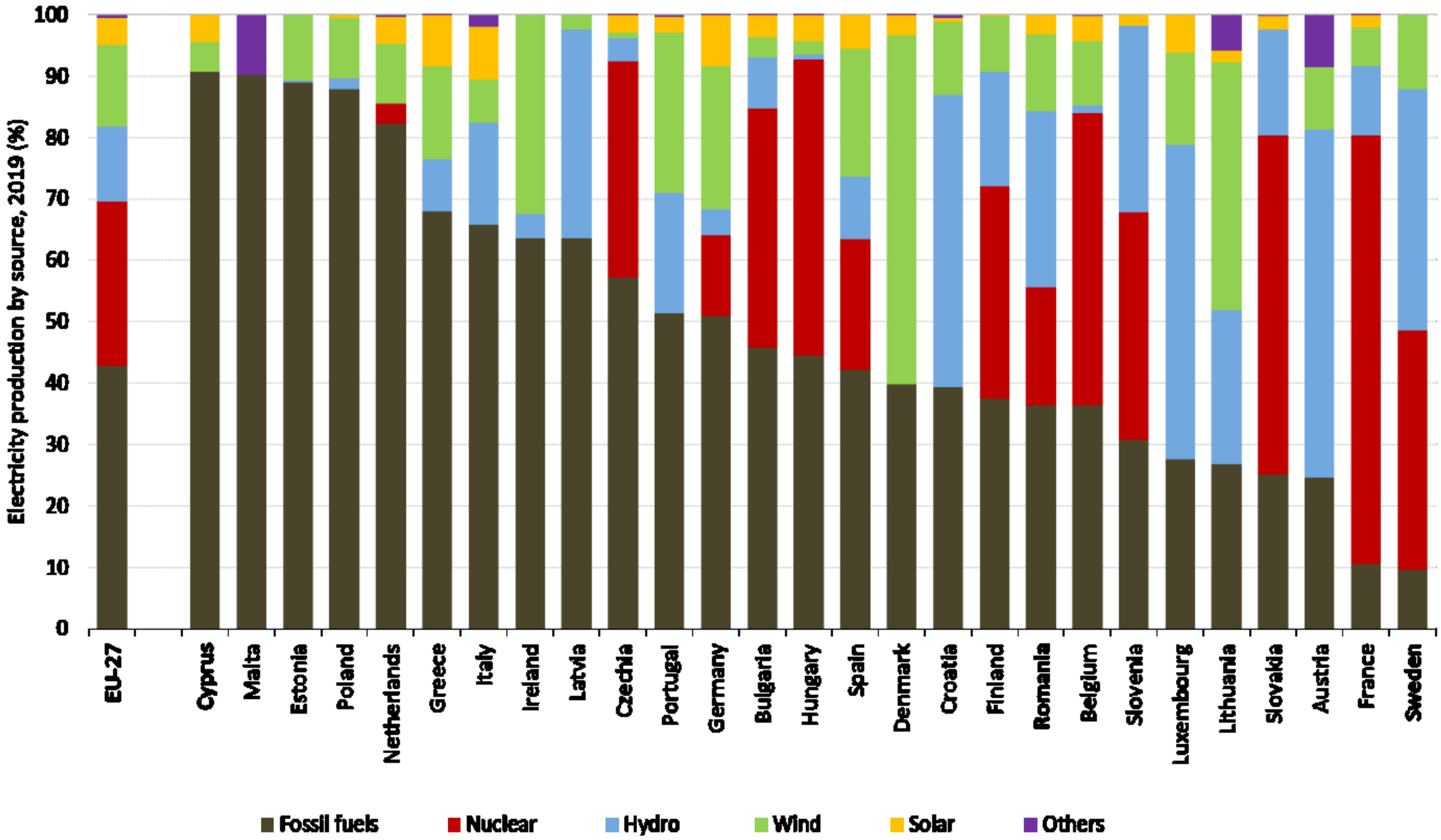


Emissions

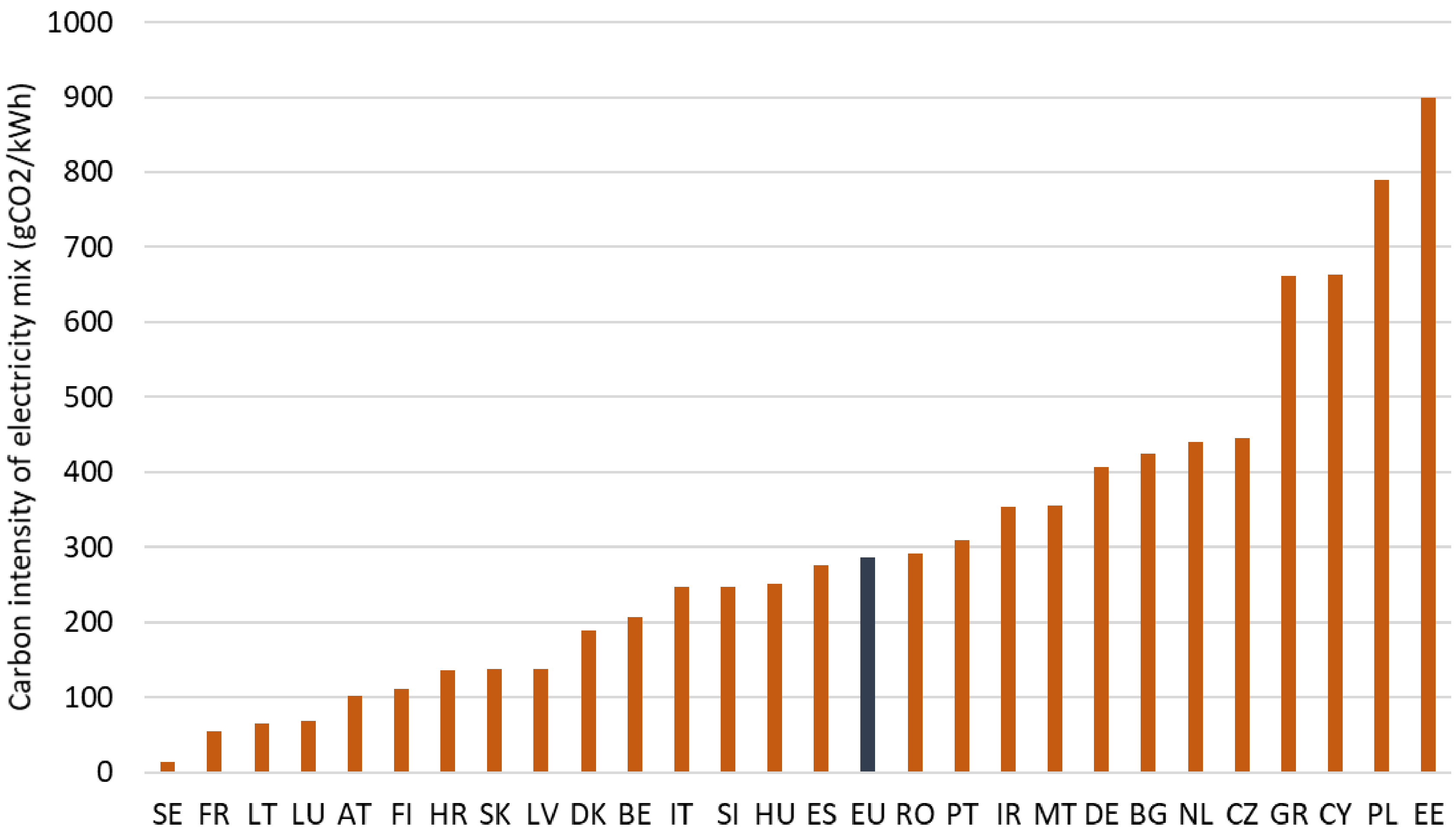


WTT-, TTW- and embedded car CO2 emissions of conventional and alternative vehicles and various energy sources

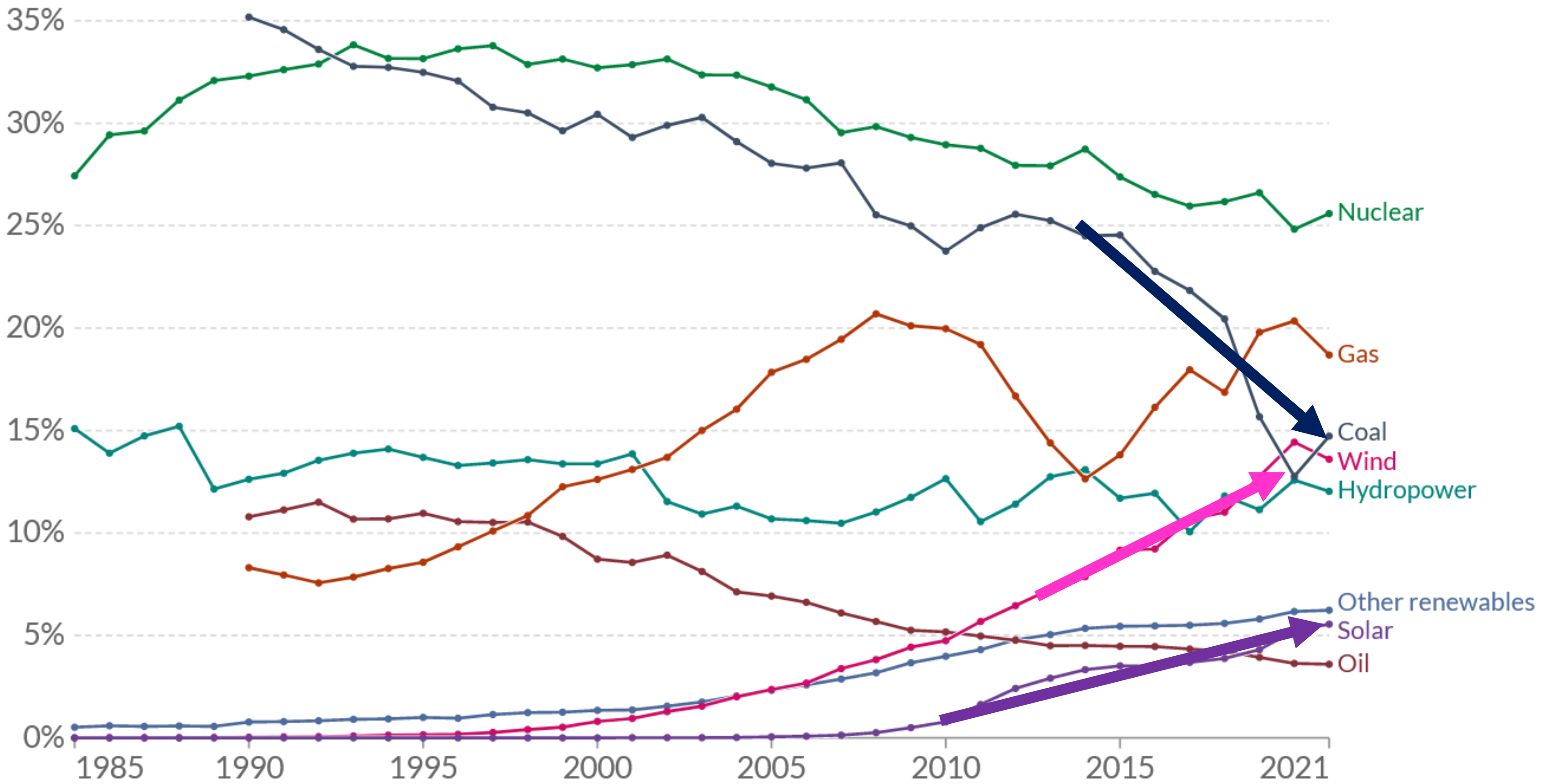
Electricity production by source



Carbon intensity of electricity generation by country



Share of electricity production by source, EU-27



Source: Our World in Data based on BP Statistical Review of World Energy & Ember

OurWorldInData.org/energy • CC BY

FCVs vs BEVs

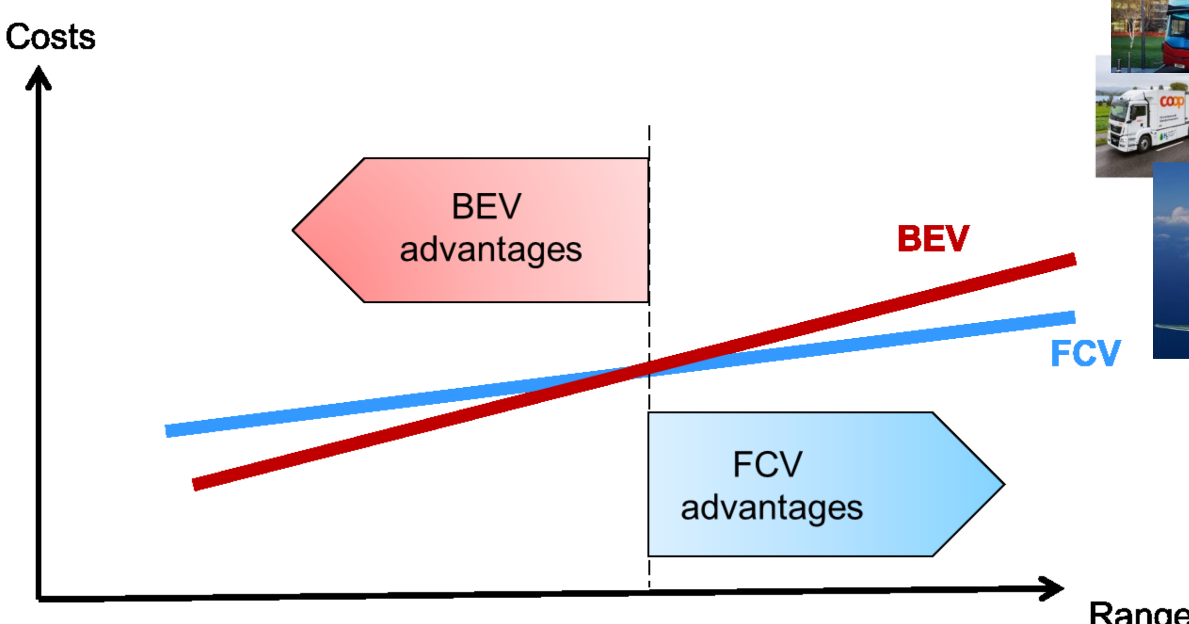
BEV

- Costs
- Infrastructure
- Fuel efficiency

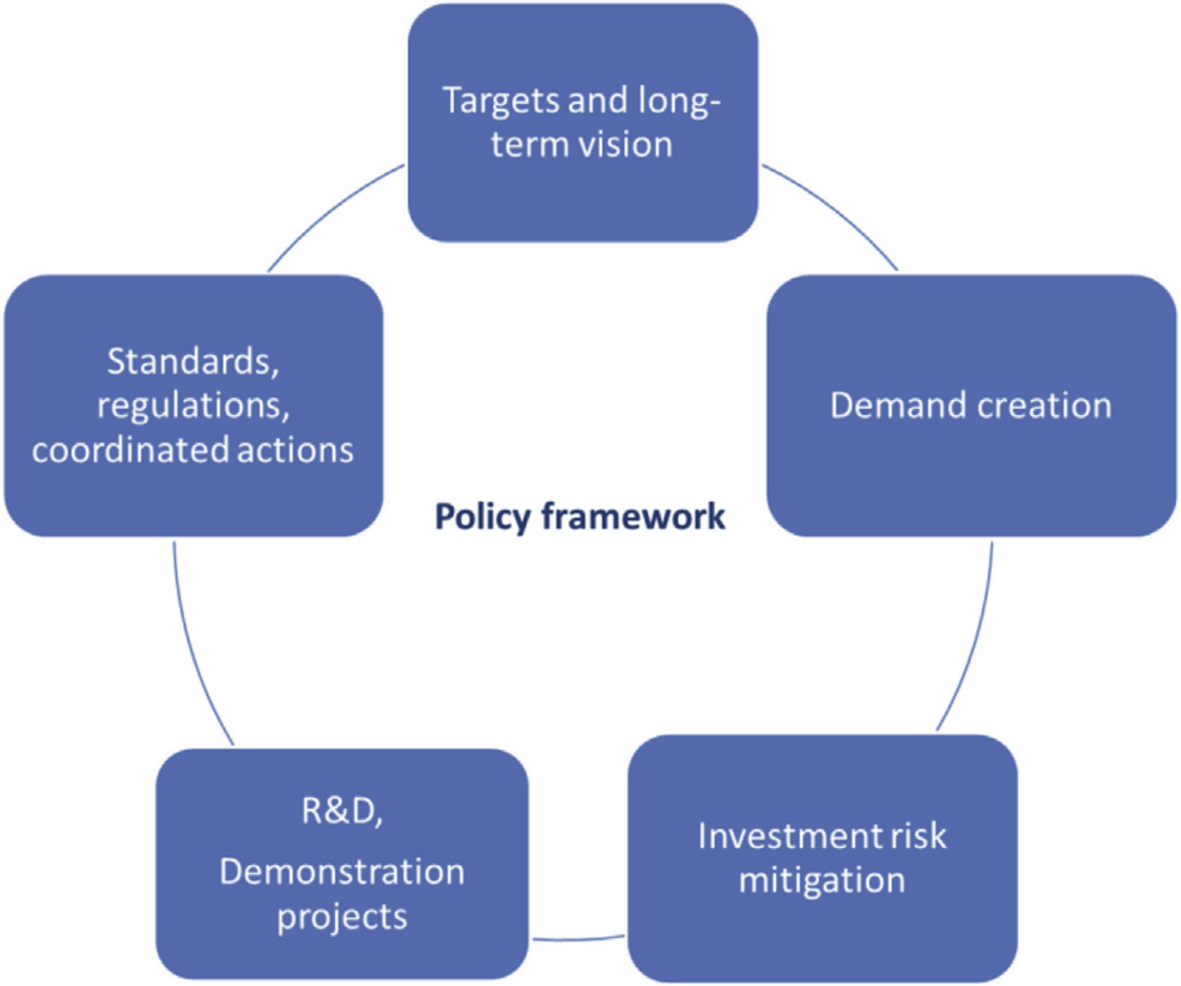
FCV

- Refuelling time
- Driving range

- Environmental benefits



Policy



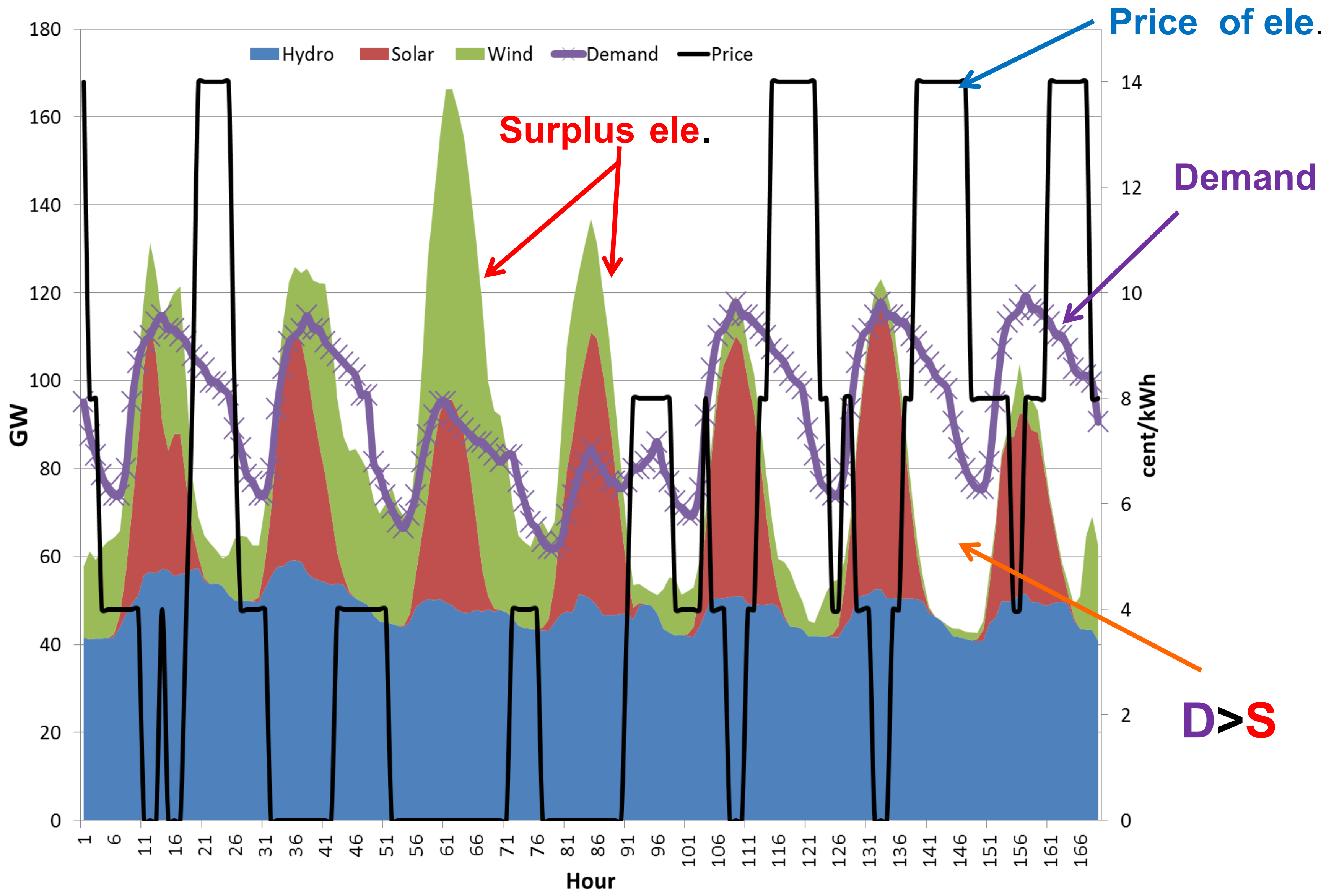
Targets and long-term vision
Demand creation
Investment risk mitigation
R&D,
Demonstration projects
Standards, regulations, coordinated actions
Policy framework

Renewable energy sources

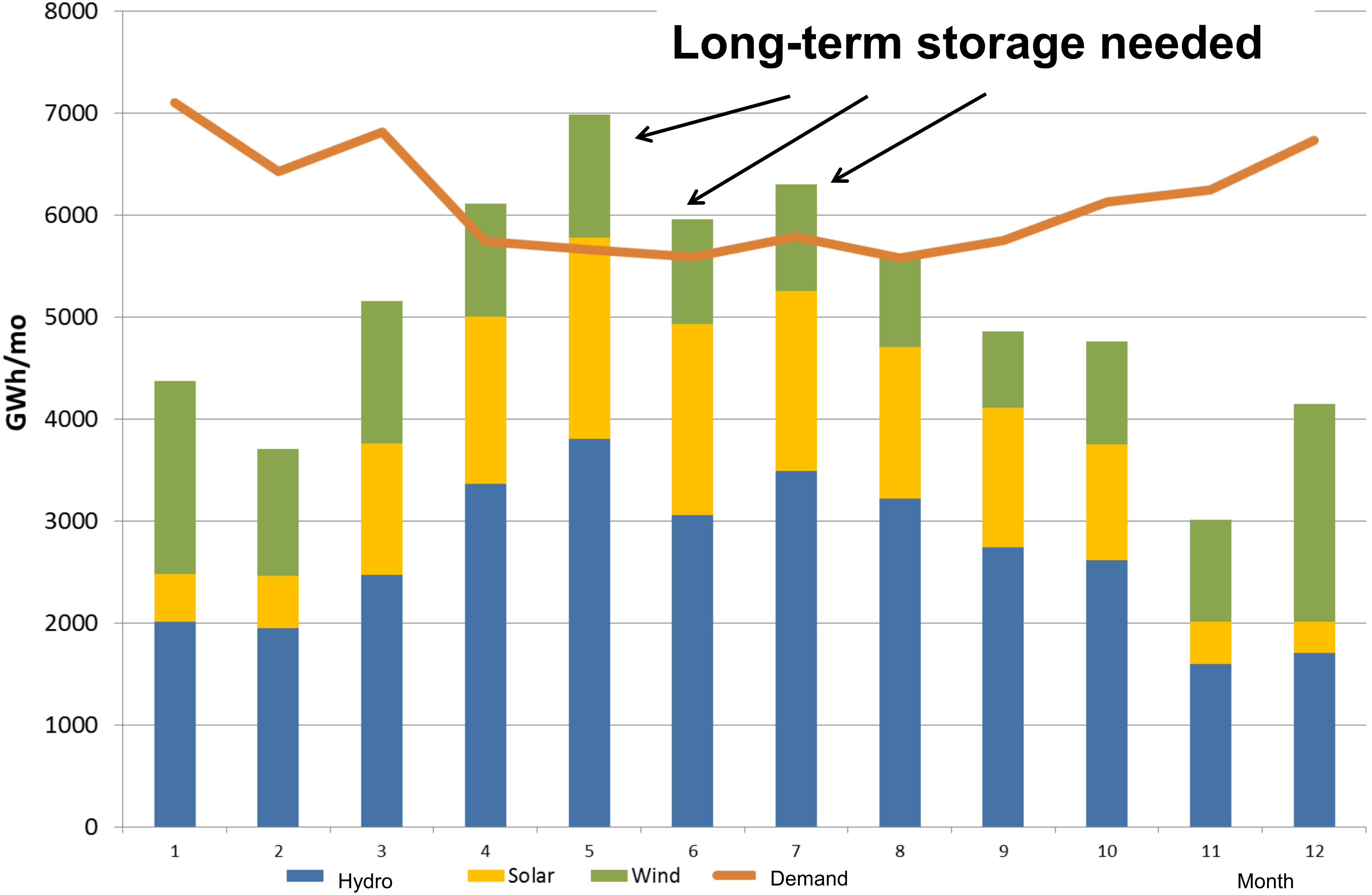
- ✓ increase the use of renewable energy sources
  - sufficient and secure energy supply
  - reduction of energy-related greenhouse gas emissions

- ❖ how to cope with excess electricity from RES

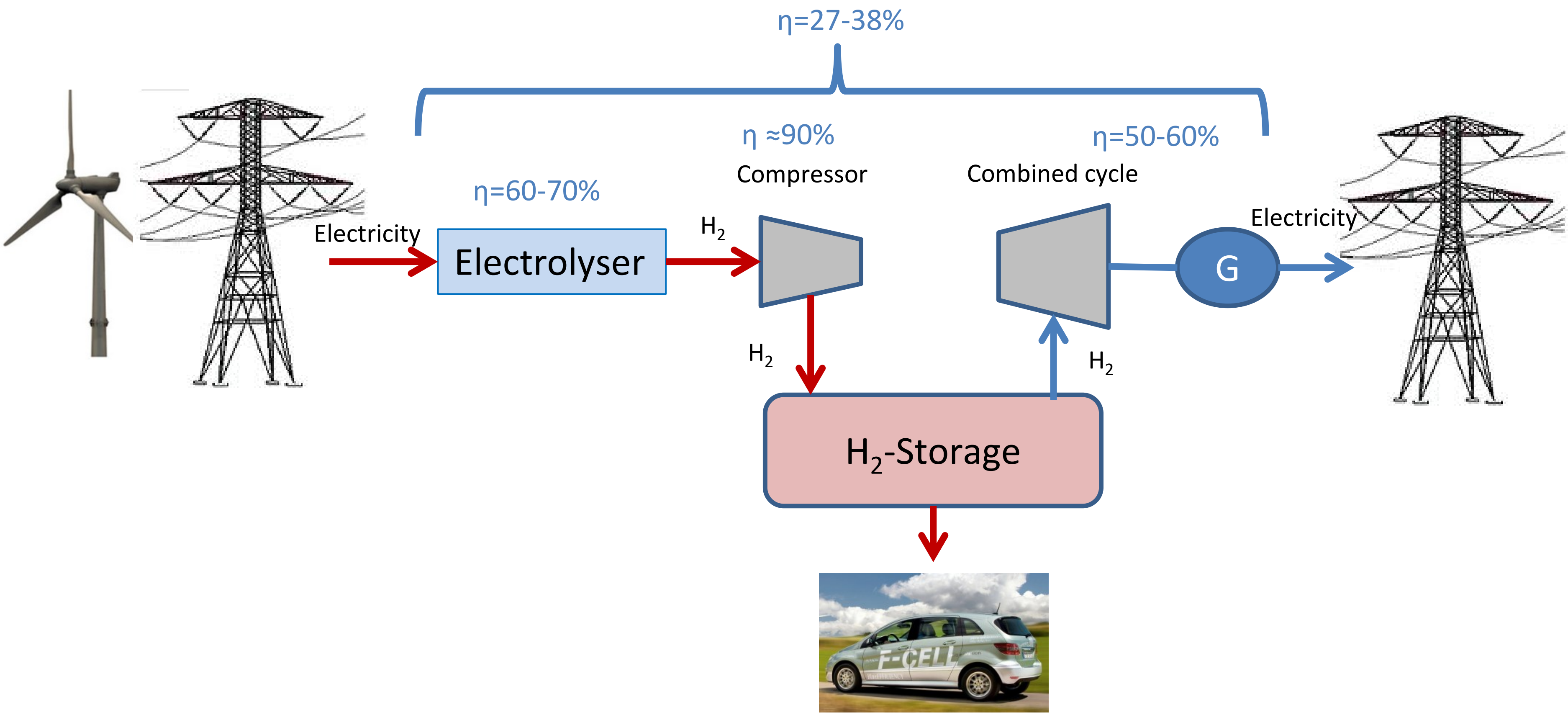
Integrating large shares of renewable electricity



Demand for long-term storage

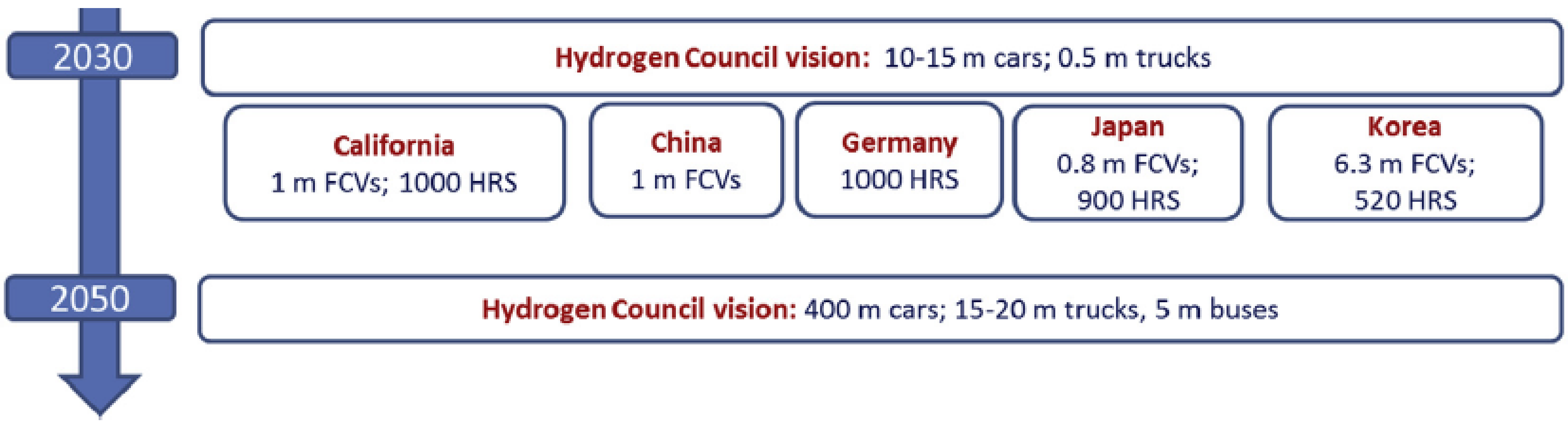


Hydrogen: storage and fuel

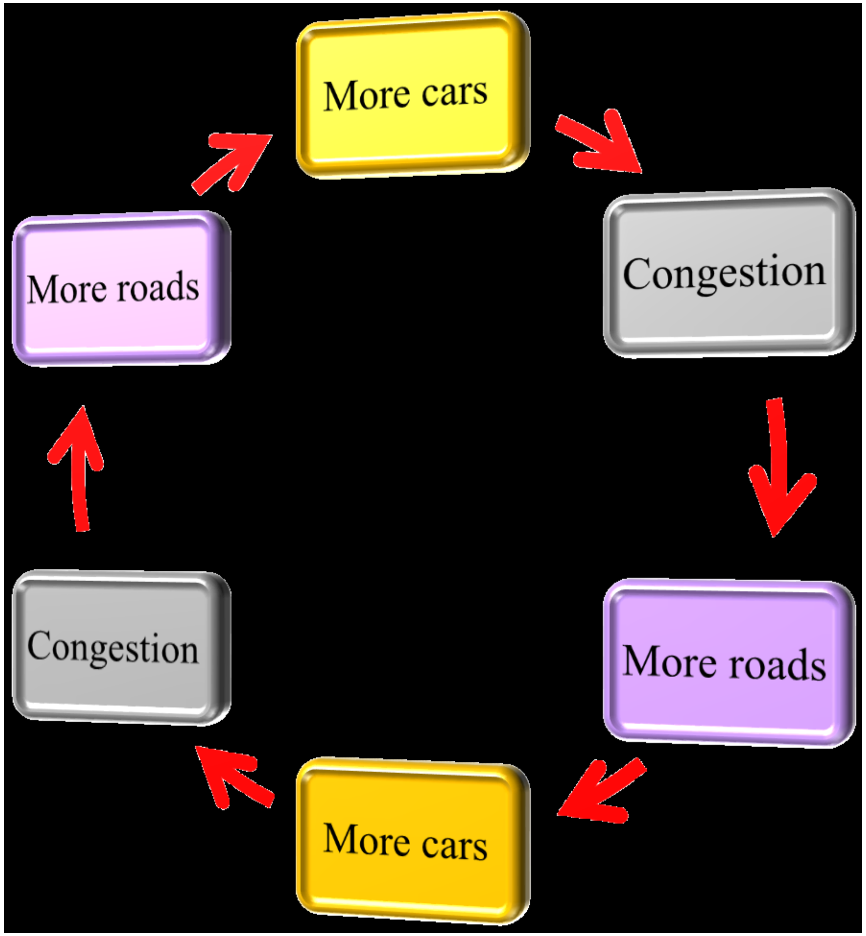


Energy supply chains: Storage and/or use of RES for mobility

Announced targets for FCV



Car-oriented mobility

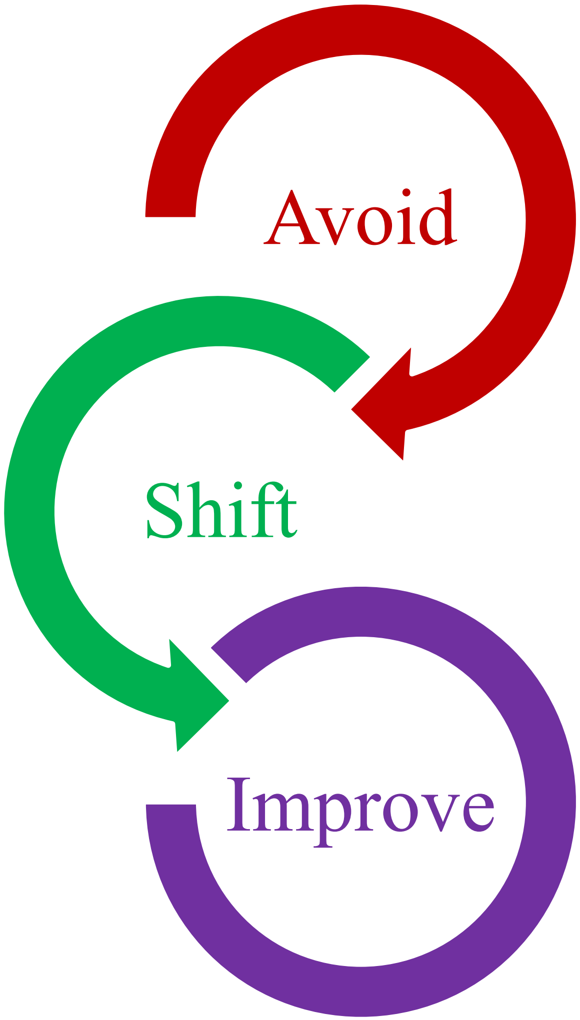


Car-oriented mobility

Car-oriented transport development

https://simotron.files.wordpress.com

Towards Sustainable Mobility



…unnecessary travel and reduce trip distances

….towards more sustainable modes

…transport practices and technologies

Conclusions

- ✓ …decarbonization of transport ….full environmental benefit – hydrogen from RES
- ✓ …integration of renewables
- ✓ …enhance energy security
- ✓ …major challenge – cost and infrastructure
- ✓ …policy framework

International Journal of Hydrogen Energy
Available online 4 March 2022
In Press, Corrected Proof

The economics and the environmental benignity of different colors of hydrogen

A. Ajanovic, M. Sayer, R. Haas

Fuel Cells
From Fundamentals to Systems

Review | Open Access

Economic and Environmental Prospects for Battery Electric- and Fuel Cell Vehicles: A Review†

A. Ajanovic, R. Haas

Energy
Volume 235, 15 November 2021, 121340

Prospects and impediments for hydrogen fuel cell buses

A. Ajanovic, A. Glatt, R. Haas

International Journal of Hydrogen Energy
Volume 46, Issue 16, 3 March 2021, Pages 10049-10058

Prospects and impediments for hydrogen and fuel cell vehicles in the transport sector

A. Ajanovic [a], R. Haas [a]

ajanovic@eeg.tuwien.ac.at