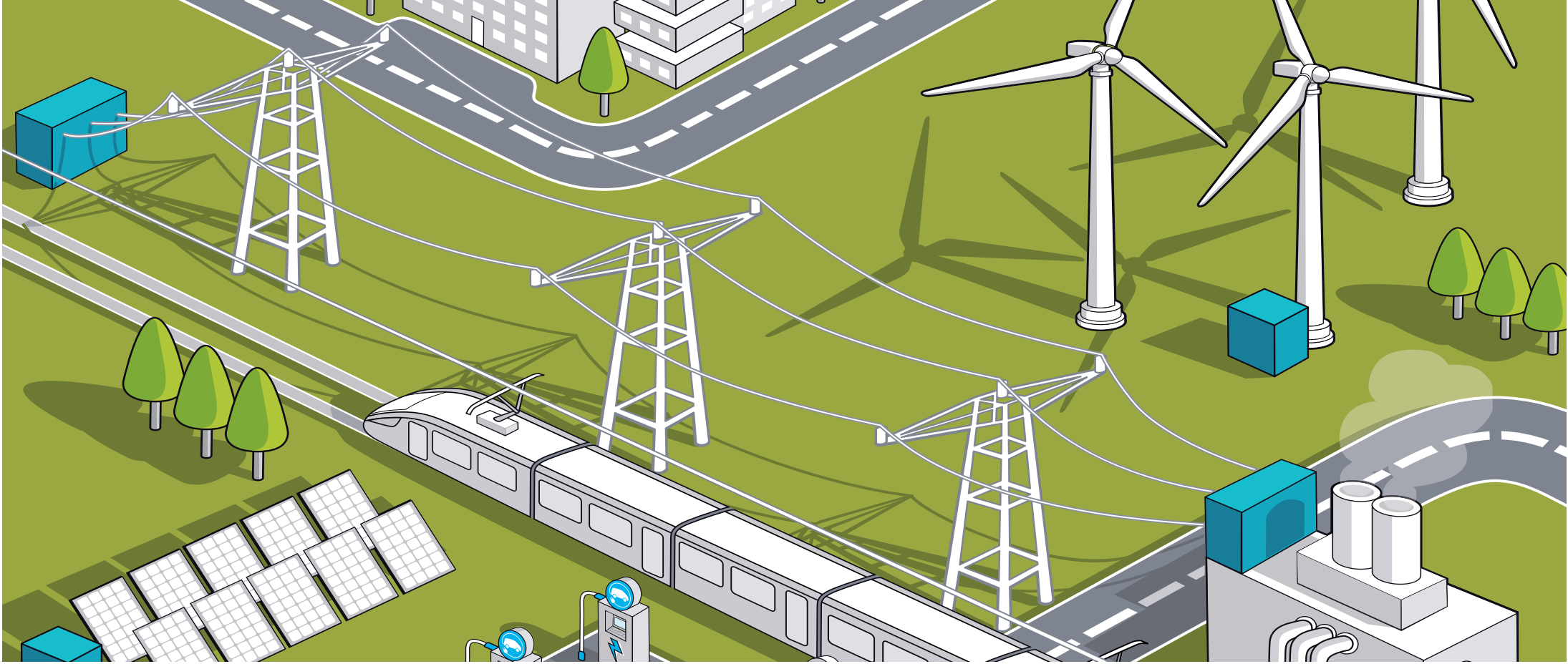


ETH Emeriti, November 25, 2019

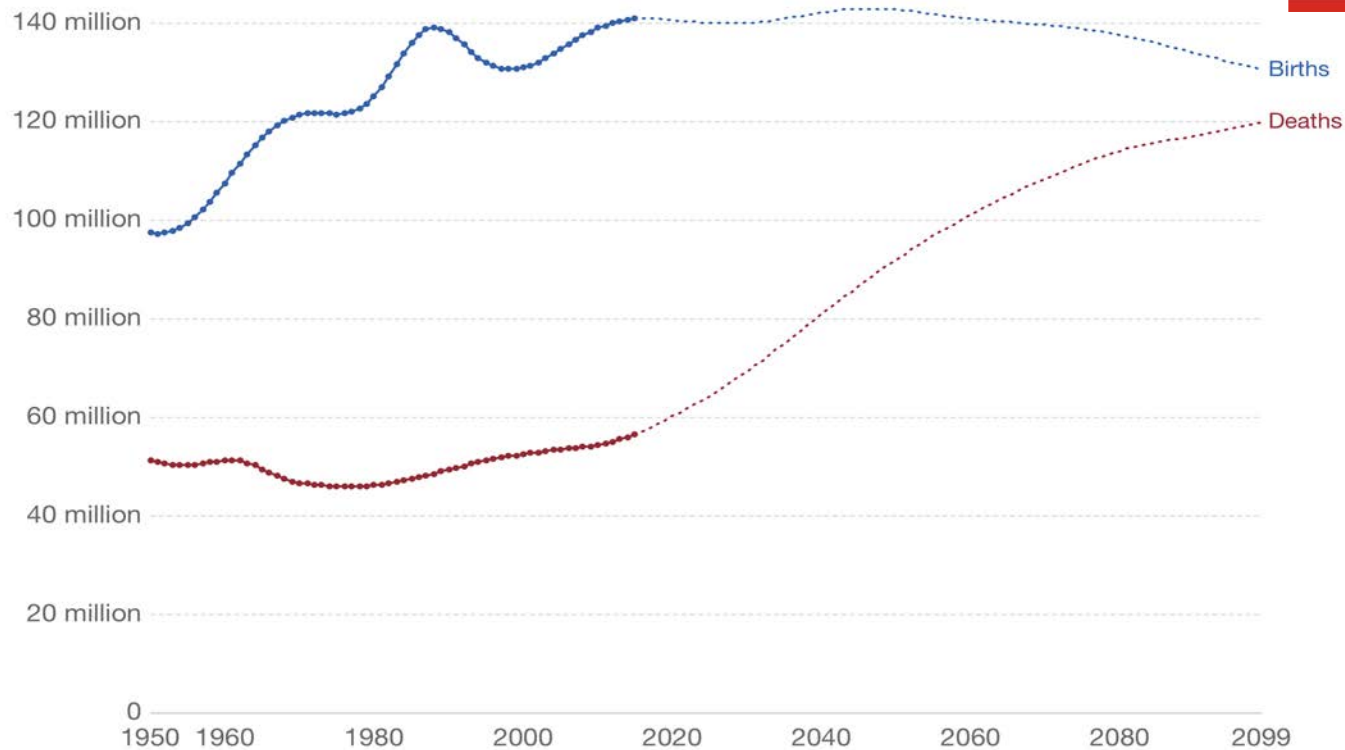
Energy and Mobility

Lino Guzzella



World Population I

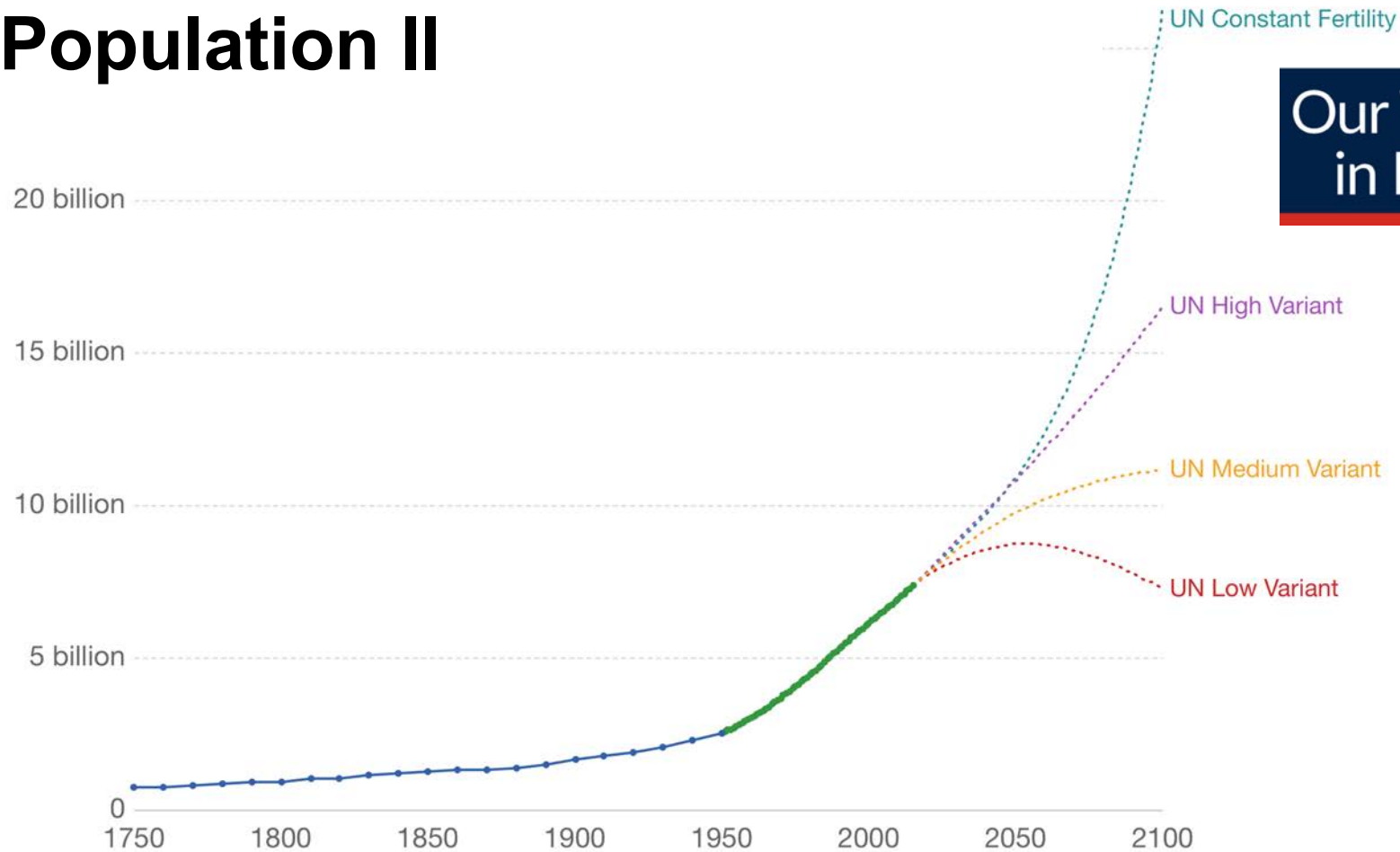
Our World
in Data



Quelle: <https://ourworldindata.org>

OurWorldInData.org/future-population-growth/ · CC BY

World Population II

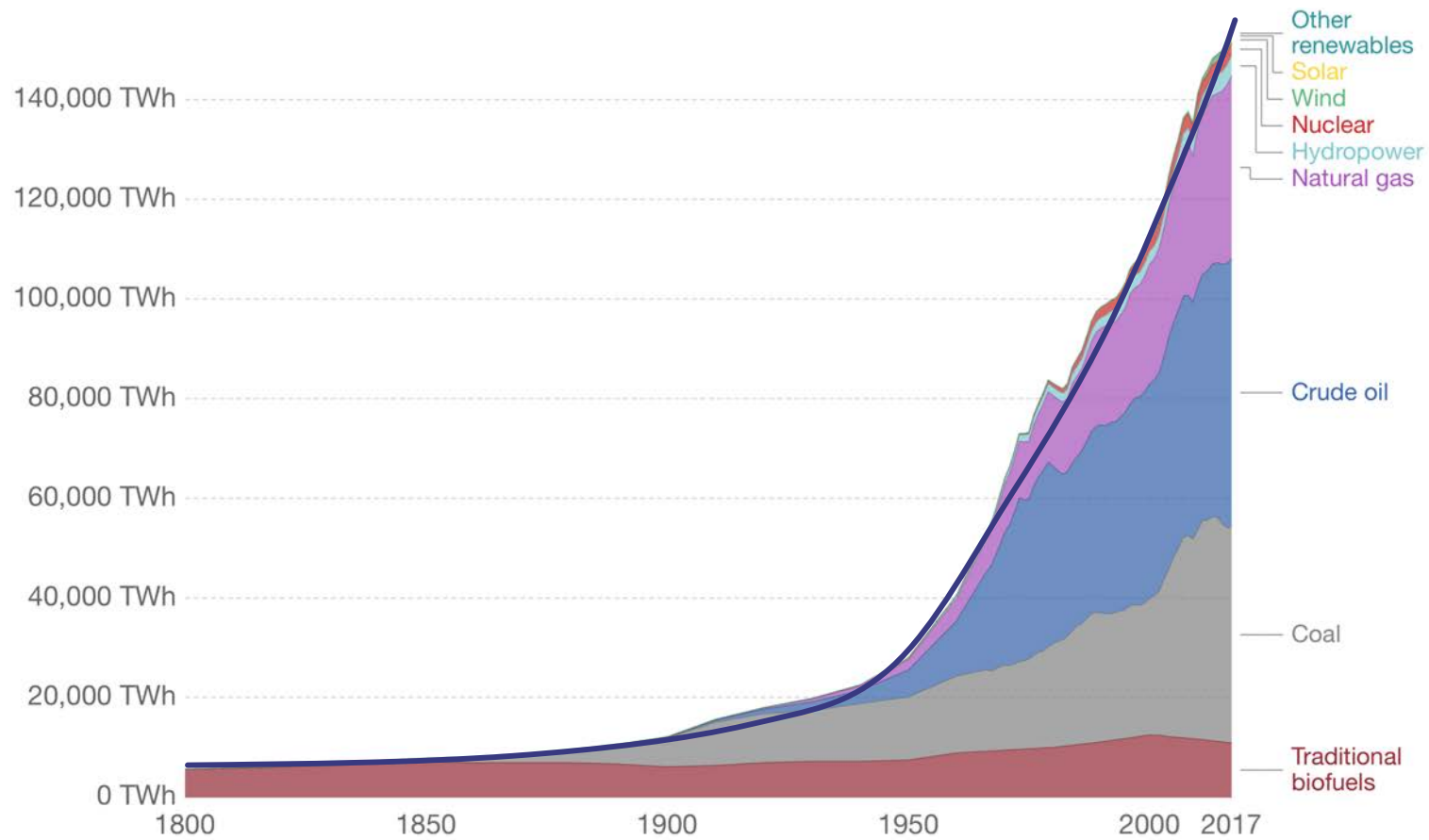


Our World
in Data

Quelle: <https://ourworldindata.org>

OurWorldInData.org/world-population-growth/ • CC BY

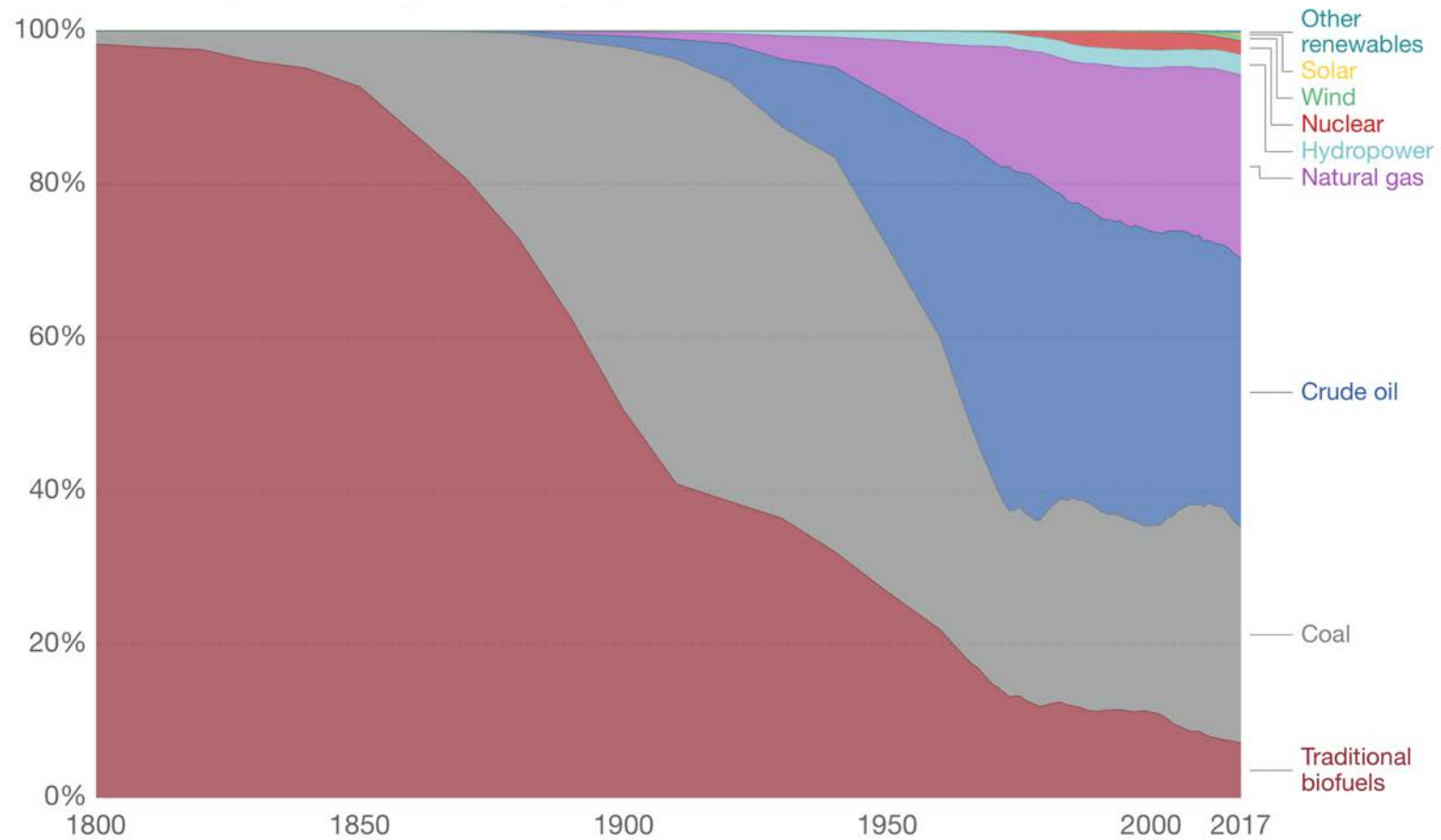
World Exergy Consumption



Source: Vaclav Smil (2017) and BP Statistical Review of World Energy

CC BY

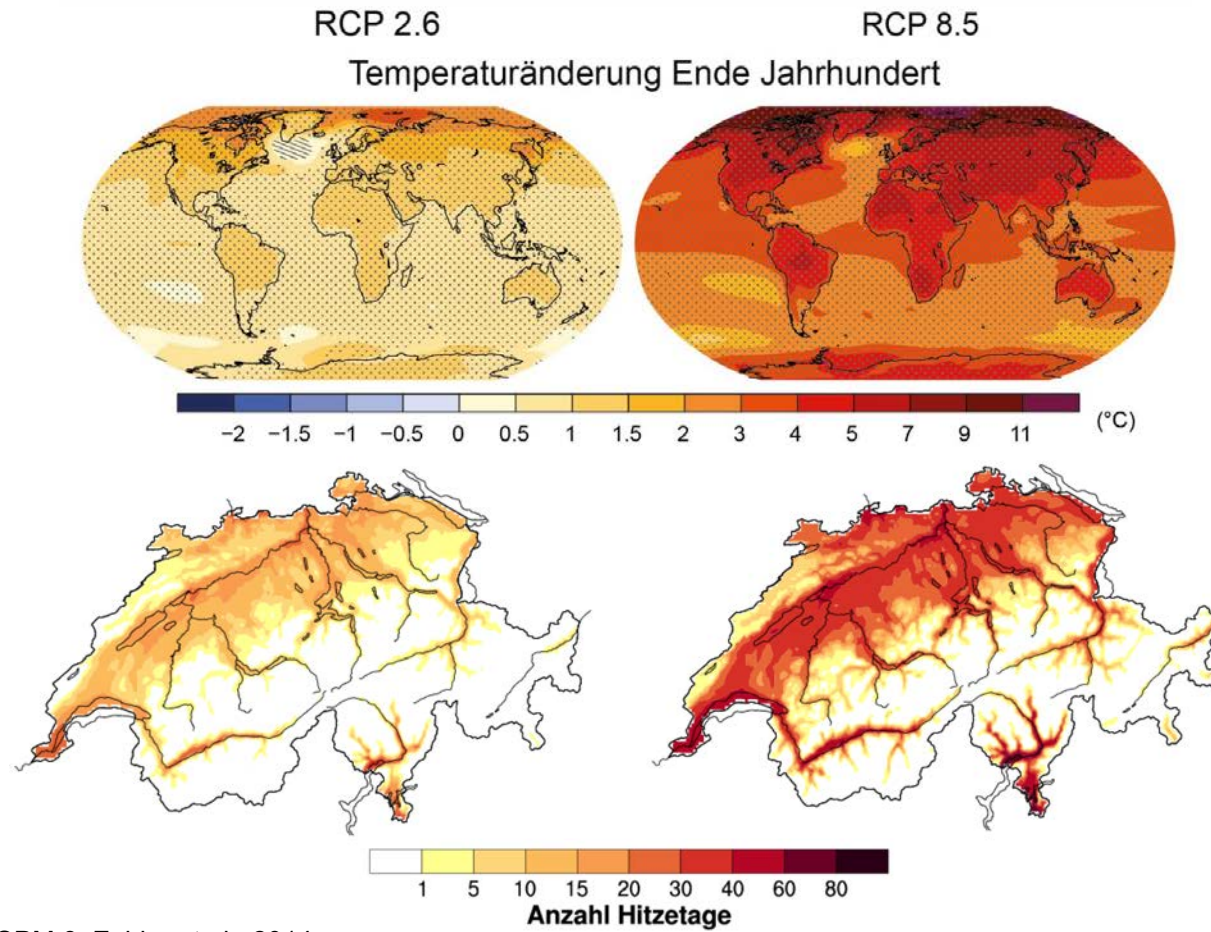
The World Relies on Fossil Exergy Carriers



Source: Vaclav Smil (2017) and BP Statistical Review of World Energy

CC BY

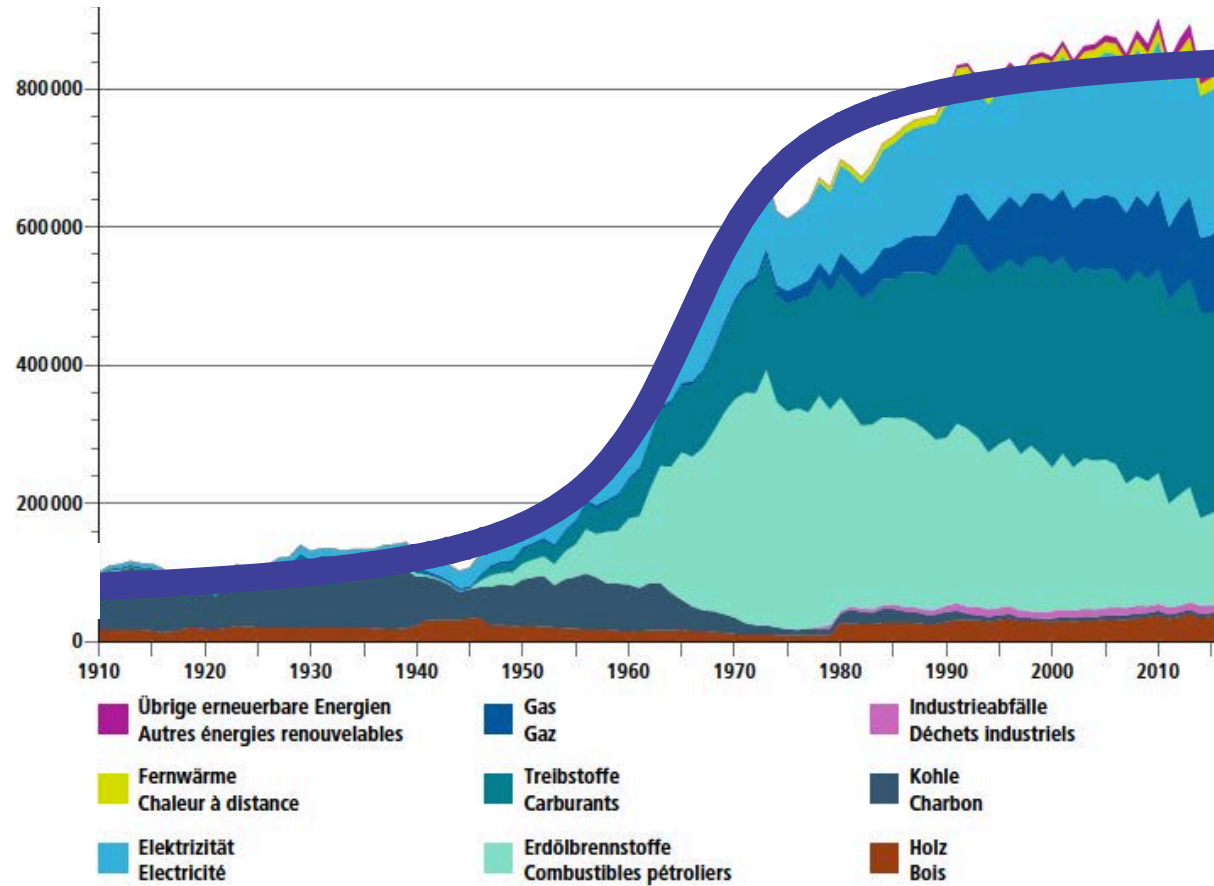
Climate Change – Local and Global Effects



Source: IPCC WG1 SPM Fig. SPM.8, Zubler et al., 2014

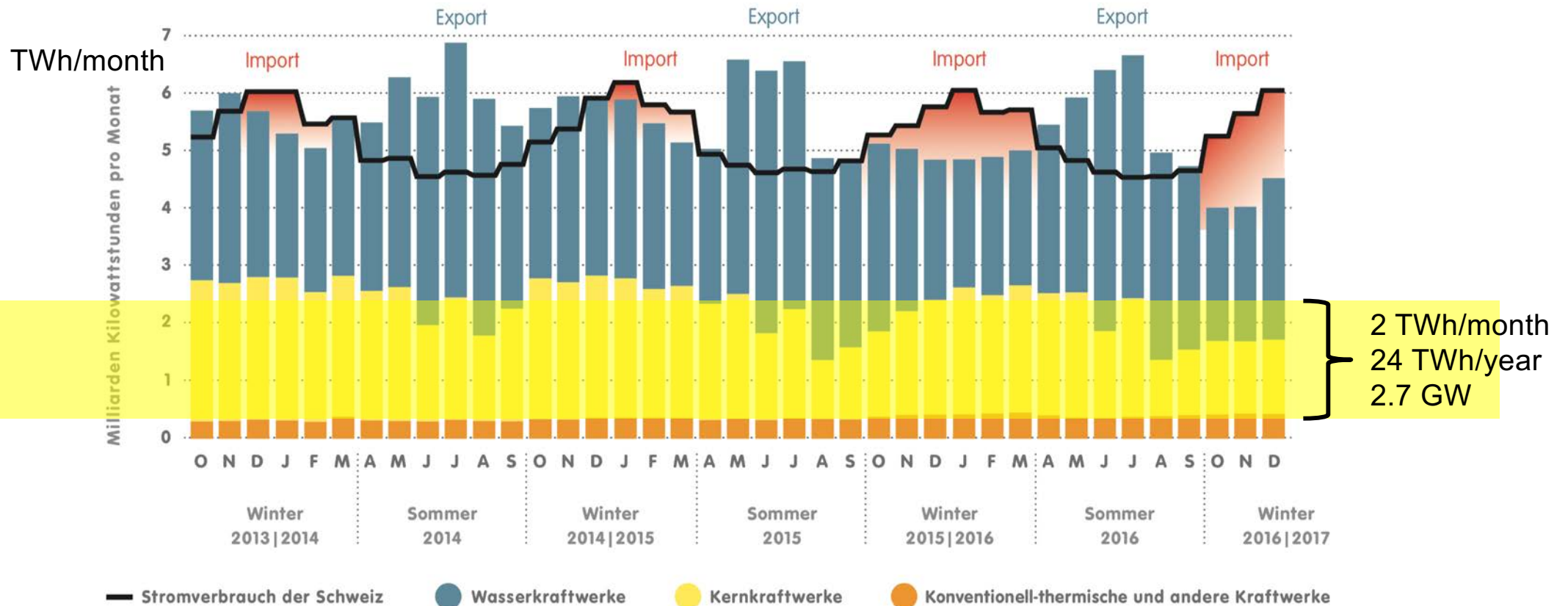
Exergy Demand – Switzerland

TJ



Source: Gesamtenergiestatistik, BfE, 2018

Electricity in Switzerland

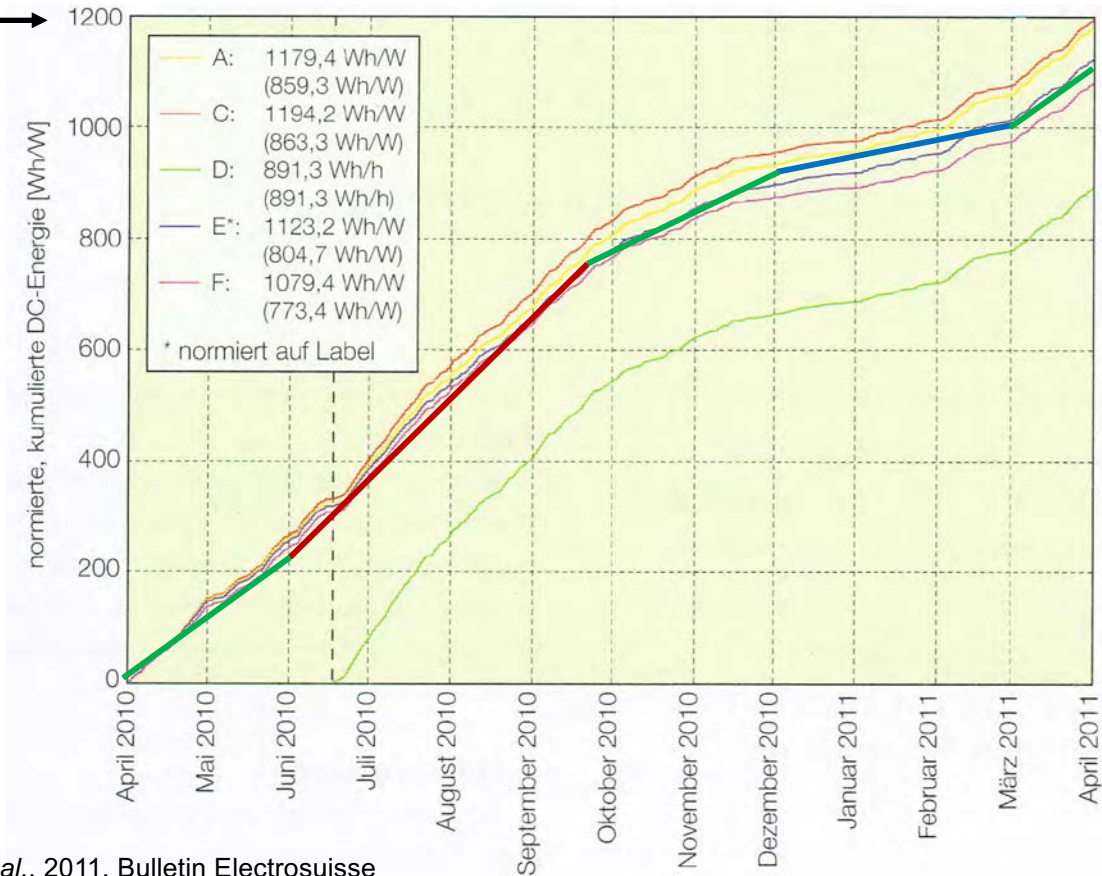


Quelle: Bundesamt für Energie, Elektrizitätsstatistik

Monthly Yield of PV in Switzerland

1'200 Wh/W ¹⁾ → 1200

Load factor:

$$\frac{1'200 \text{ Wh}}{1 \text{ W } 8'880 \text{ h}} = 14\%$$


Simplification:

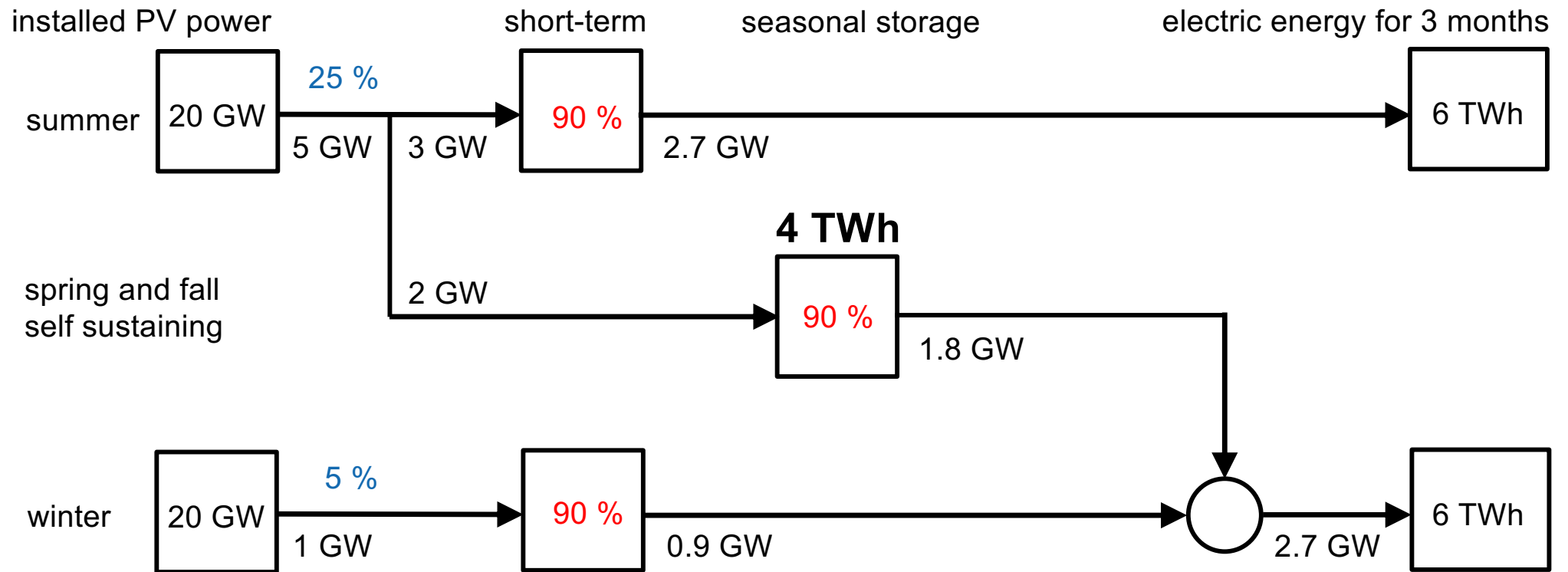
- 15% spring
- 25% summer
- 15% fall
- 5% winter

Mean load factor: 15%

CH Reality:²⁾ 11%

Source: ¹⁾ F. Baumgartner *et al.*, 2011, Bulletin Electrosuisse
²⁾ Swisssolar, Faktenblatt, April 2019

Replacing CH-Nuclear and Imports with PV



Batteries as Seasonal Storage?



Source: <https://www.ekz.ch/de/ueber-ekz/newsroom/medienmitteilungen-2018>

Reality Check EKZ Volketswil

- Cost plant 6 Mio. CHF
- Power 18 MW
- Stored electric energy 7.5 MWh
- Area required 450 m²

- » Seasonal storage of 4 TWh requires 560'000 such plants
- » Cost 3'360 billions CHF (GNP CH 2018 was 690 billions CHF)
- » Required area 250 km² (30'000 "Stade de Suisse" soccer arenas)

All figures with ■ see: <https://www.ekz.ch/de/ueber-ekz/newsroom/medienmitteilungen-2018>

Pumped Storage Hydraulic Power Plants (PSHPP)?



Source: <https://www.axpo.com/psw-limmern.html>

Reality Check AXPO Linth-Limmern PSHPP

- Cost 2.1 billion CHF¹⁾
 - Pumps and turbines power 1 GW
 - Stored electric energy 39 GWh
- » Seasonal storage of 4 TWh requires 100 LL-PSHPP
- » Required pump power 8 GW
- » Required turbine power 2 GW
- » Cost several 100 billions CHF
- » Sensitive alpine environment

Quellen: ¹⁾ All figures with ■ see: <https://www.axpo.com/psw-limmern.html>

Overview

	PV	Cost Converter	Cost storage	Other issues
Batteries	20 GW	0	+++++	resources, area
PSHPP	20 GW	+	+++	alpine environment
H ₂	23 GW	++	++	safety, acceptance
CH ₄	25 GW	+++	+	CO ₂ source

Caveat: Many details need further analysis



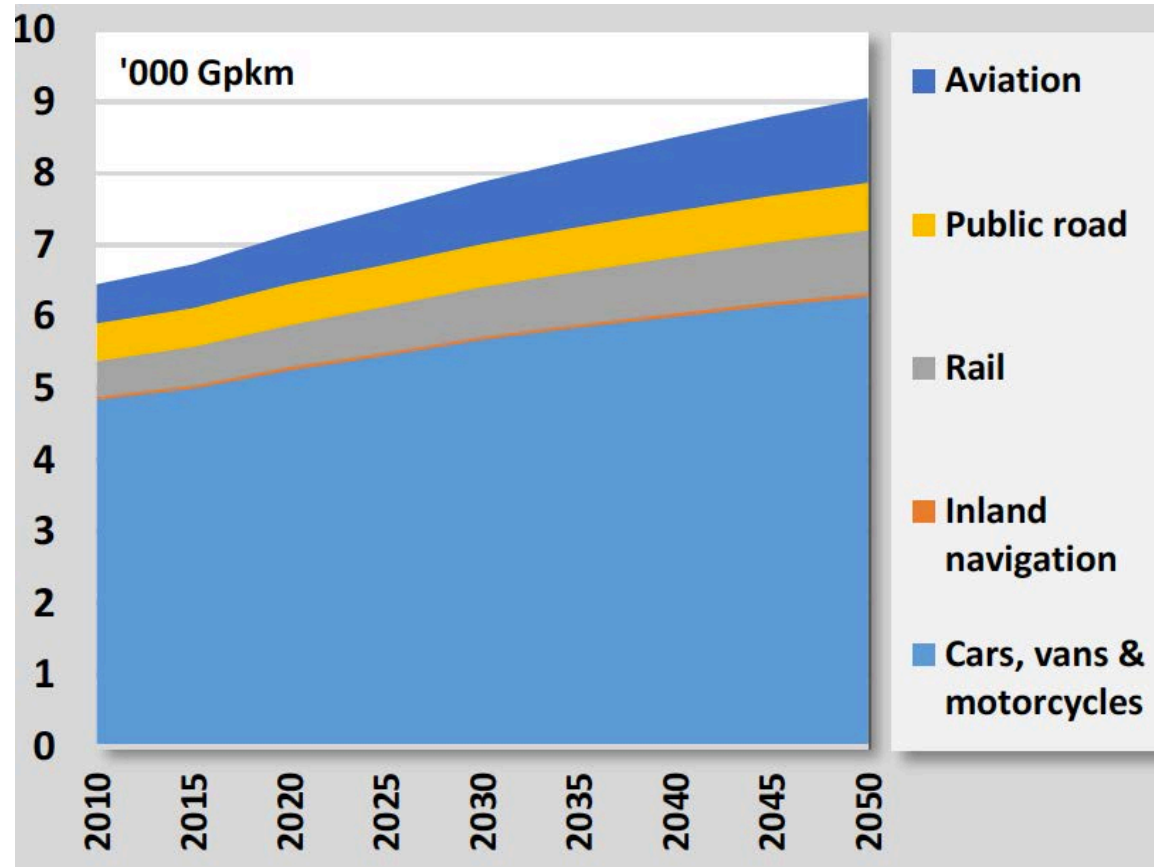
Richard Feynman (1918–1988)

«For a successful technology,
reality must take precedence
over public relations, because
nature cannot be fooled.»

On the occasion of the Rogers Commission hearing
investigating the Challenger accident, 1986

Mobility of People – The EU as an Example

Gpkm = billions of kilometers travelled by one person



Aviation
260 (short) g CO₂/pkm
150 (long)

Public road
50 g CO₂/pkm

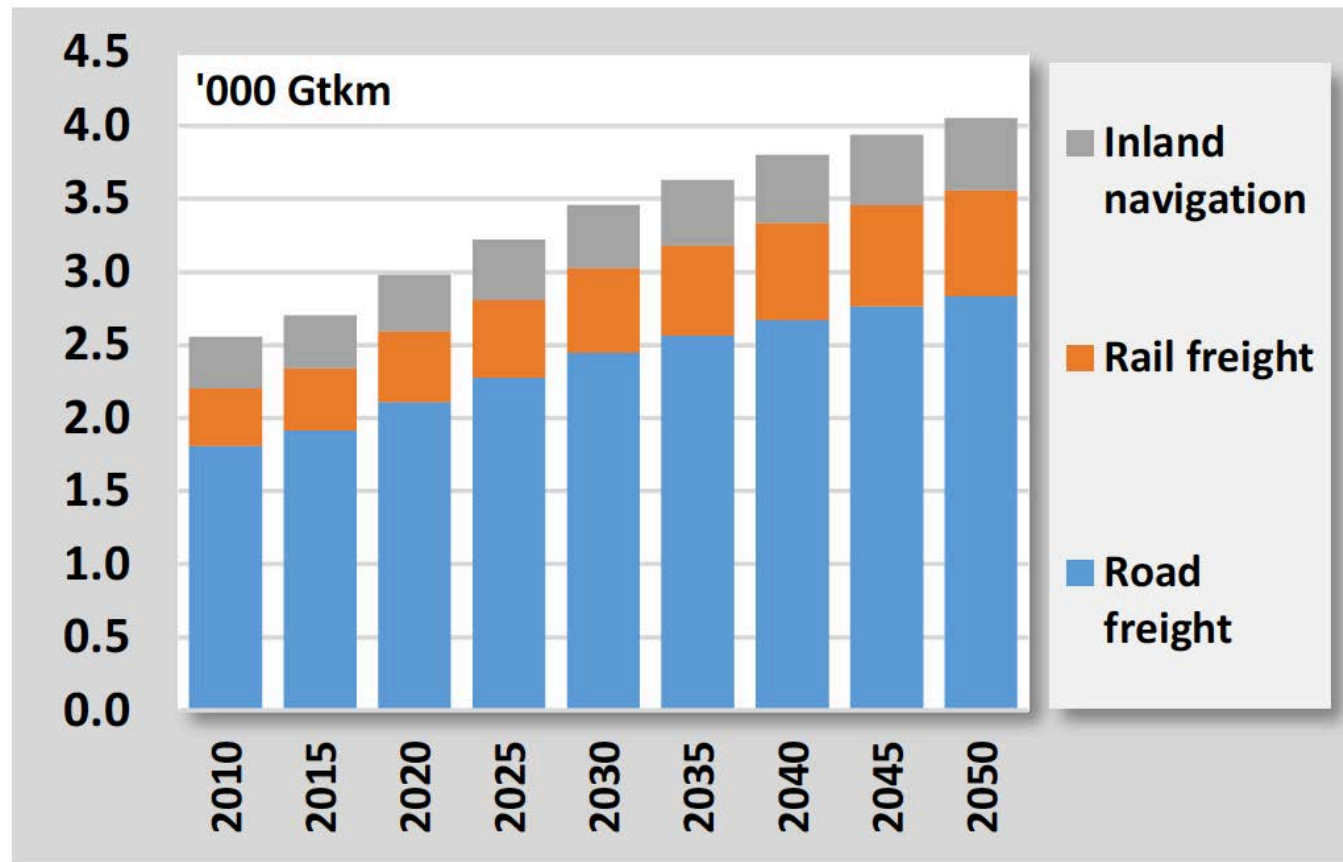
Rail
7 g CO₂/pkm (electric)
75 g CO₂/pkm (Diesel)

Inland navigation
N.A.

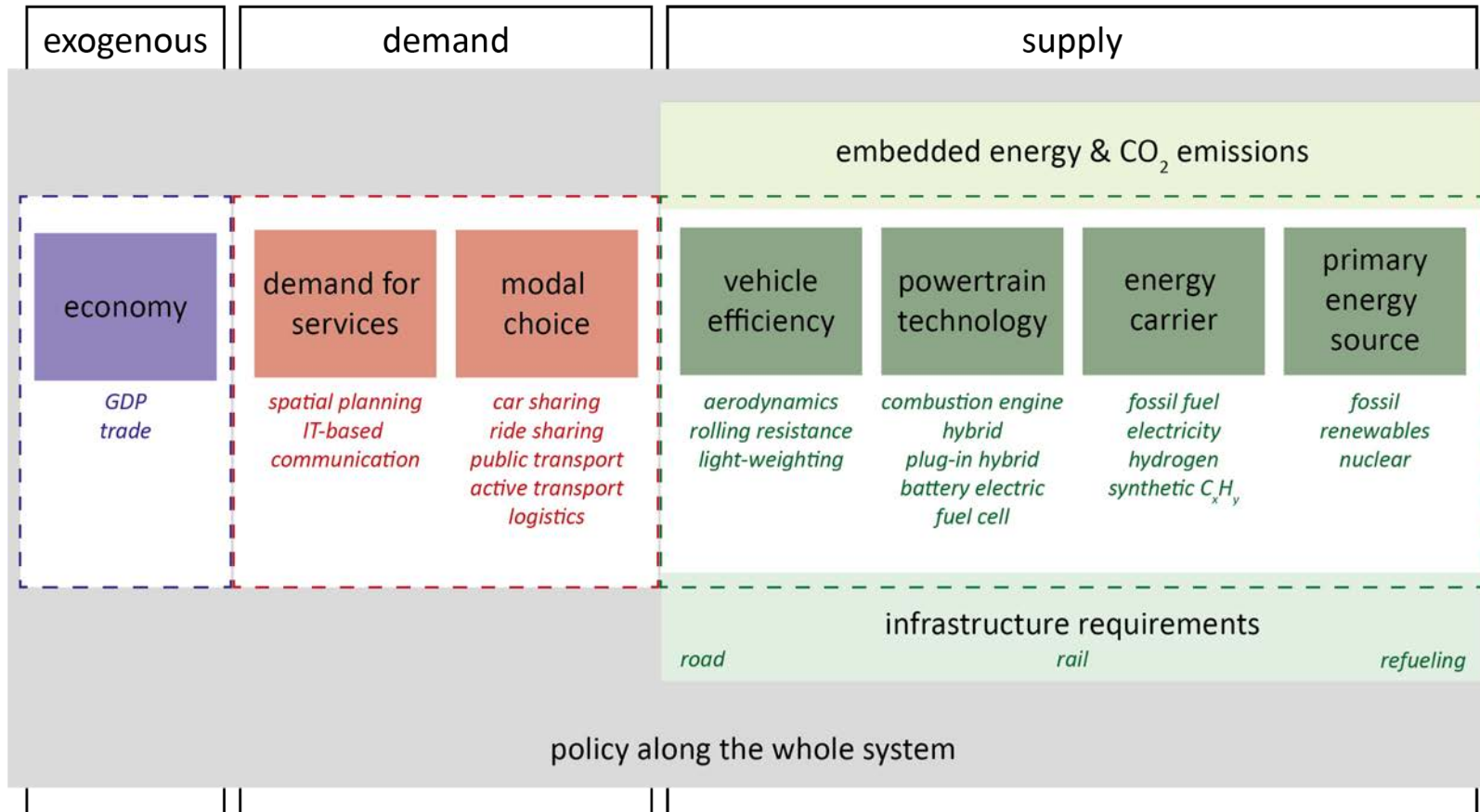
Cars, vans & motorcycles
75 g CO₂/pkm

Mobility of Goods – The EU as an Example

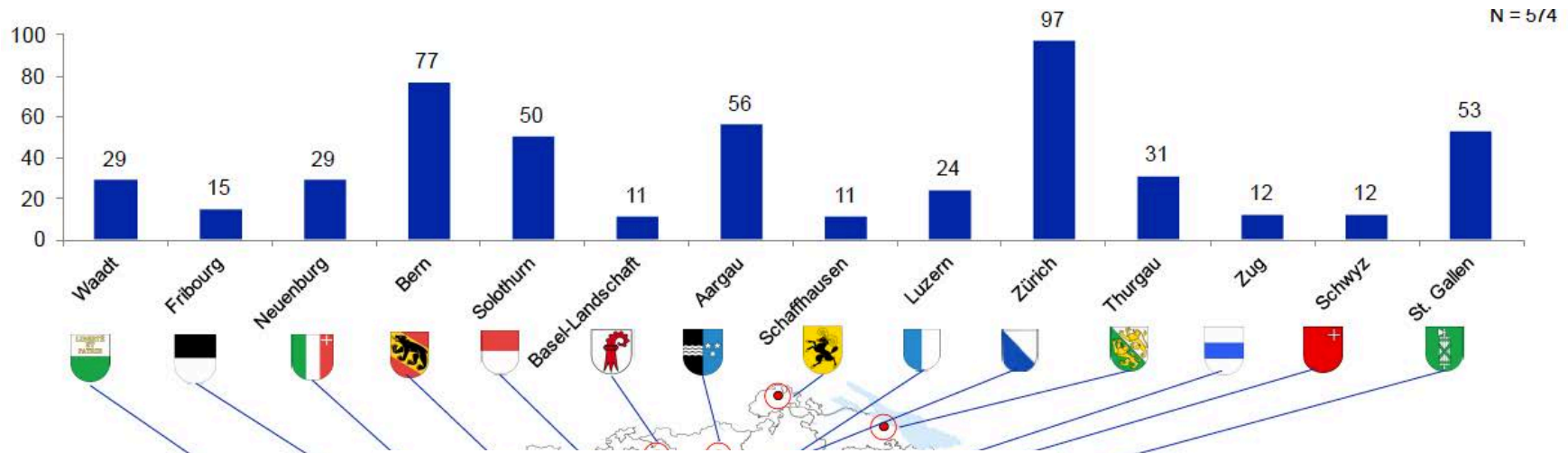
Gtkm = billions of kilometers of 1 ton of goods transported



Mobility – A Complex Issue ...



Switzerland – An Automotive Powerhouse ...



Total 574 enterprises
with 12.3 billion CHF turnover
and 34'000 employees

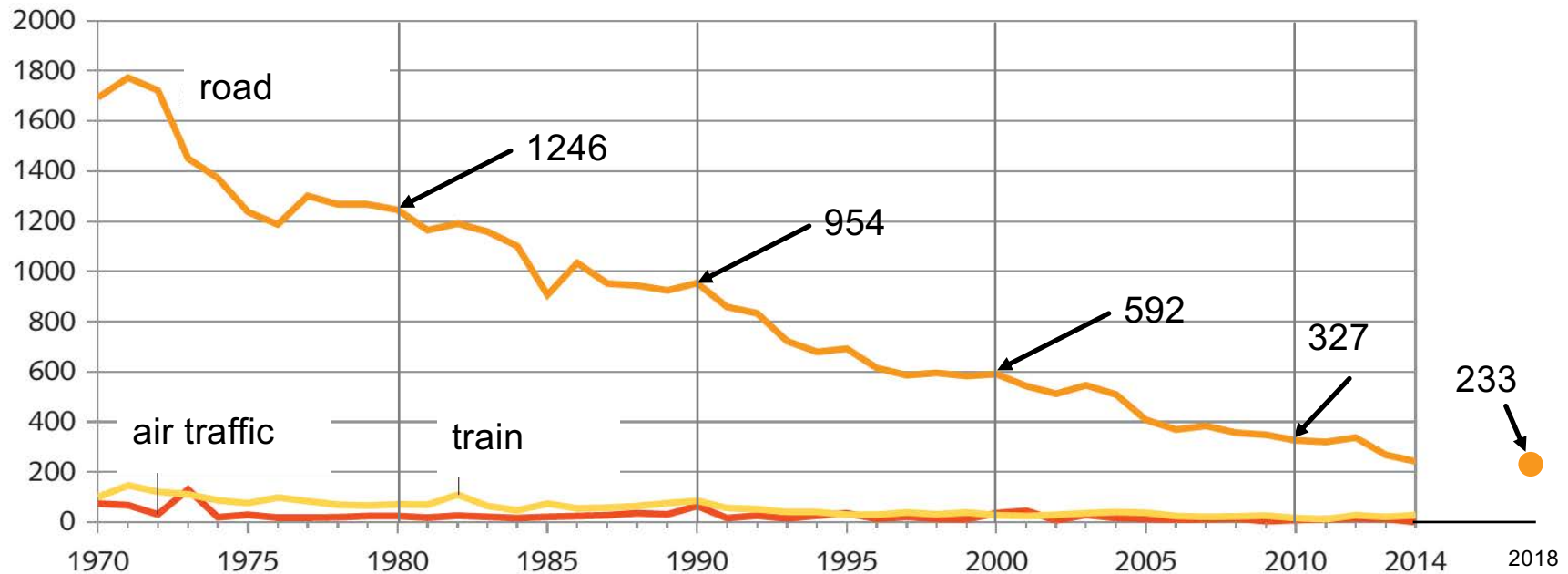
> 10 Firmen pro Kanton



Source: UZH swiss CAR Analyse „Automobil(zuliefer)industrie Schweiz 2018/19“

Fatalities – Road, Air and Train Switzerland

Tödlich verunfallte Personen nach Verkehrsträgern

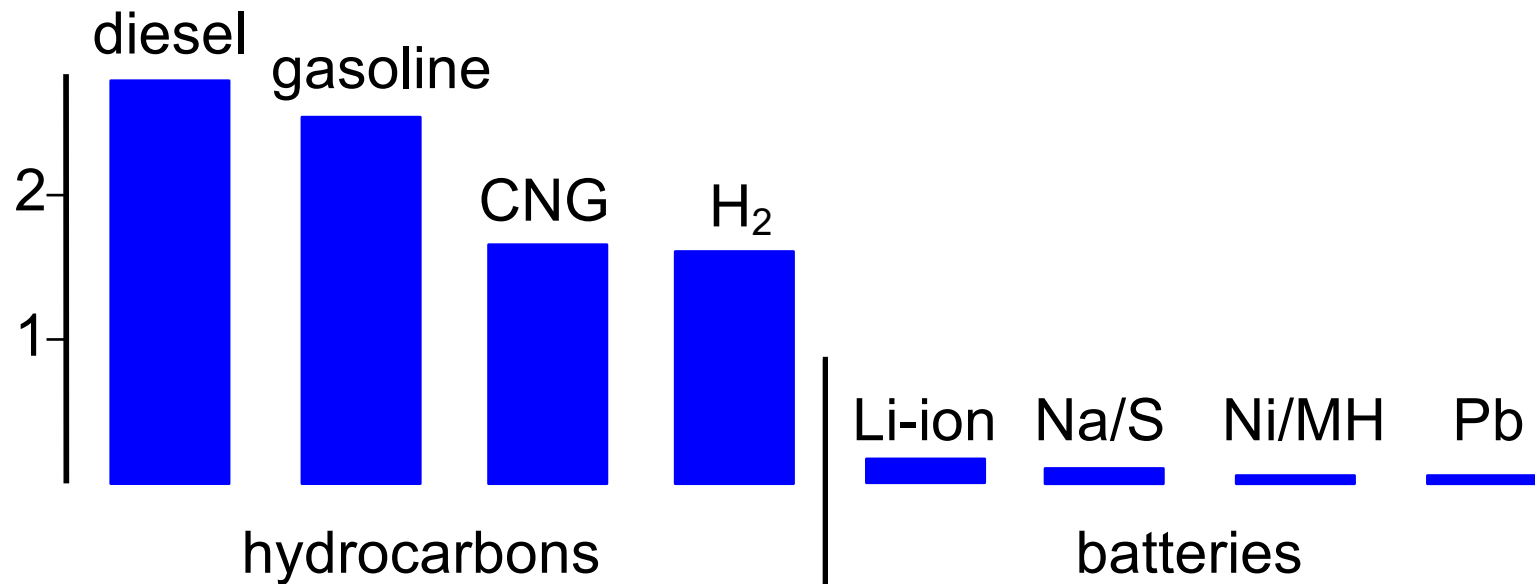


Suizide werden in der Statistik nicht berücksichtigt. Im (seltenen) Fall von Kollisionen zwischen Eisenbahnzügen und Strassenverkehrsmitteln werden die Opfer bei beiden Verkehrsträgern aufgeführt.

Quellen: ASTRA, BFS – Strassenverkehrsunfälle (SVU); BAV – Sicherheitsbericht; SUST – Flugunfallstatistik

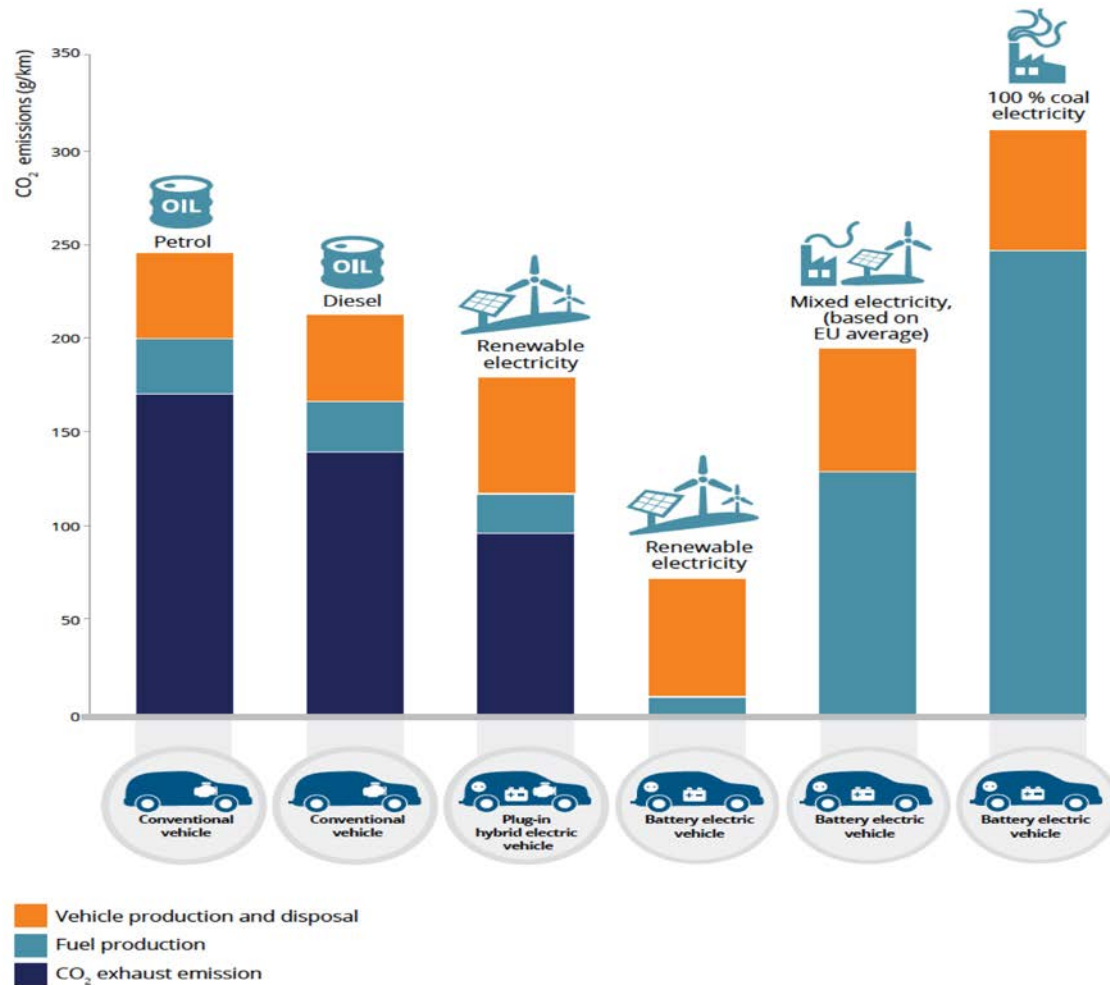
© BFS, Neuchâtel 2015

Energy Densities of Various «Fuels» – Net Value¹



1): Including “tank” mass and average “tank-to-wheel” losses; units: energy / mass [kWh/kg]

Lifetime CO₂ Emissions – ICE vs. BEV



Source: EEA, Electric Vehicles in EU, 2016

The Economist's View on CO₂-Emissions

Car	Golf 2.0 TDI, 112 kW	eGolf, 102 kW
Price	27'000 €	40'000 € - 4'000 € subsidy
Consumption ¹⁾	6.2 l Diesel/100 km	17.5 kWh/100 km
Range, Refueling	890 km, 3 minutes	200 km, 1-17 hours
Lifetime CO ₂ Emission	40 tons (250'000 km)	0 tons ²⁾ (250'000 km)

Cost of CO₂ reduction $9'000 \text{ €} / 40 \text{ t CO}_2 = 225 \text{ €} / \text{t CO}_2$

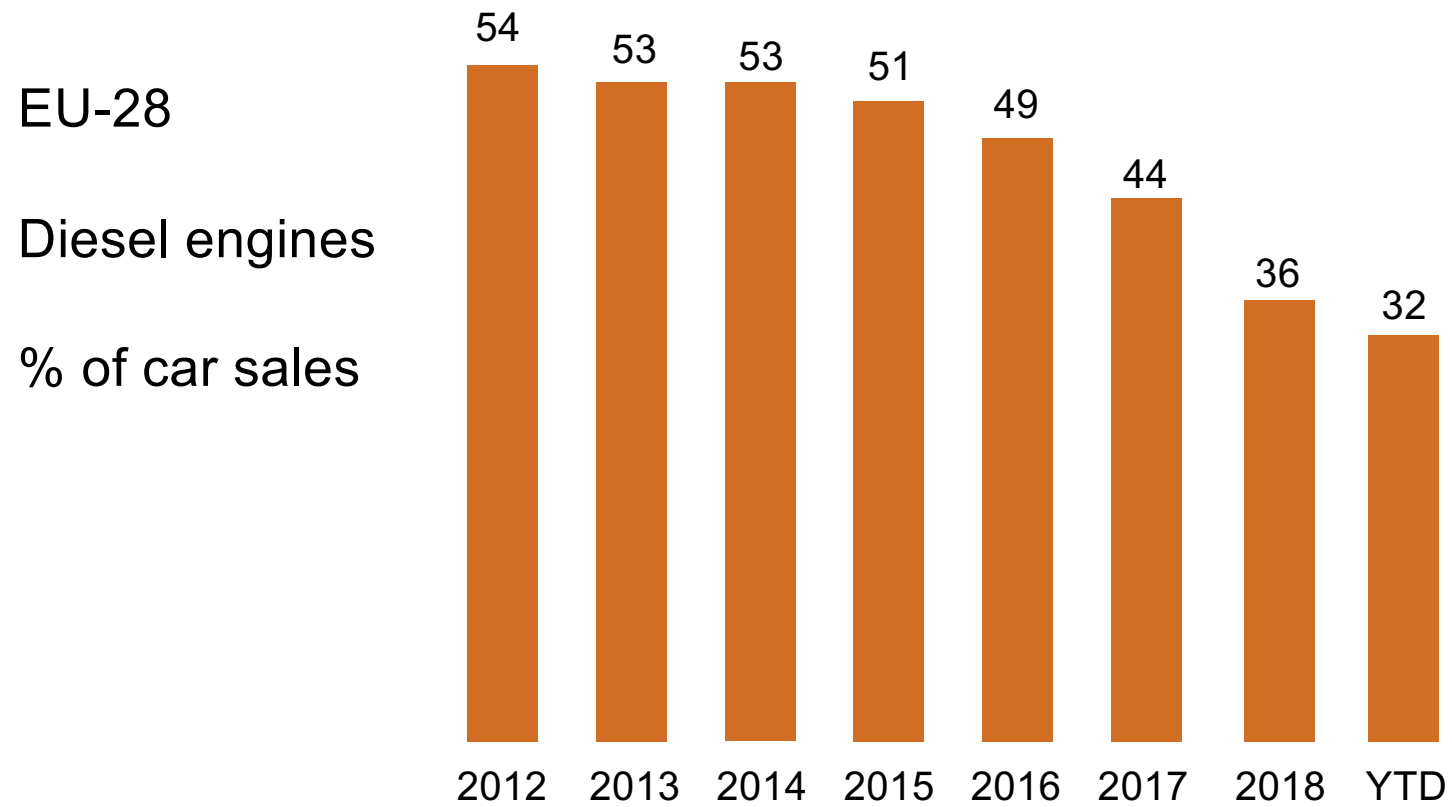
Alternatives: CO₂ certificates³⁾ = 26 €/t CO₂

1) All data "Autotest" 2018 (real road data)

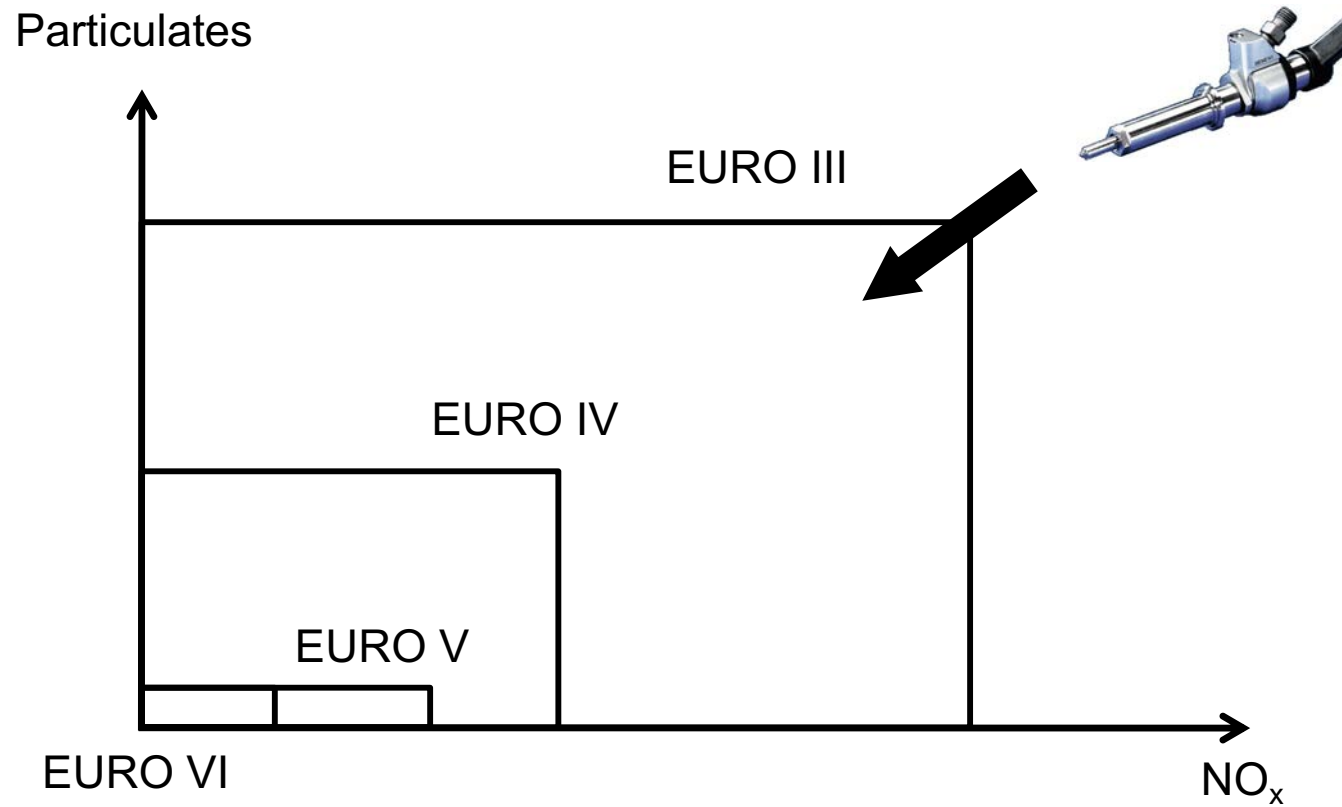
2) Assuming electricity with 0 g CO₂ / kWh and no additional "grey CO₂" caused by battery manufacturing, electricity in Germany produces 527 g CO₂/kWh

3) "myclimate", Mai 2019

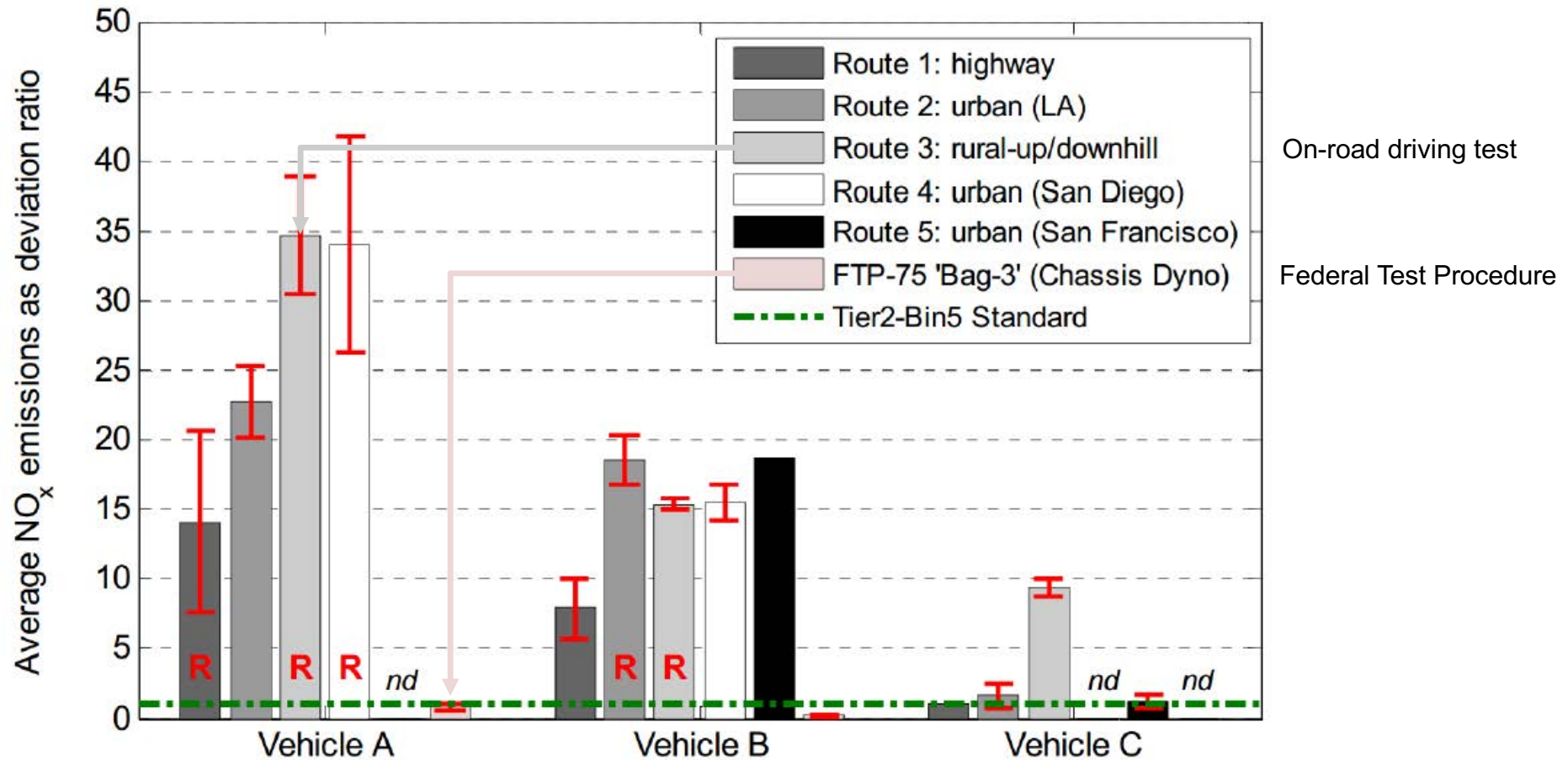
Sale New Diesel Cars



Emission Limits Diesel Engines – EU Legislation



Emission Diesel Engines – Practice



Source: International Council on Clean Transportation and West Virginia University, 2012

Climeworks – Renewable “E-Fuels” Demonstrator



Source Climeworks, 2019

Demonstration of large-volume energy storage with Power-to-X

Plant type:	DAC-3
CO₂ capacity:	410 kg/day
CO₂ application:	Methane synthesis
Heat source:	Heat recovery from synthesis
Location:	Troia, Italy
Commissioning:	1 st Oct 2018

Electricity Cost as Main Driver

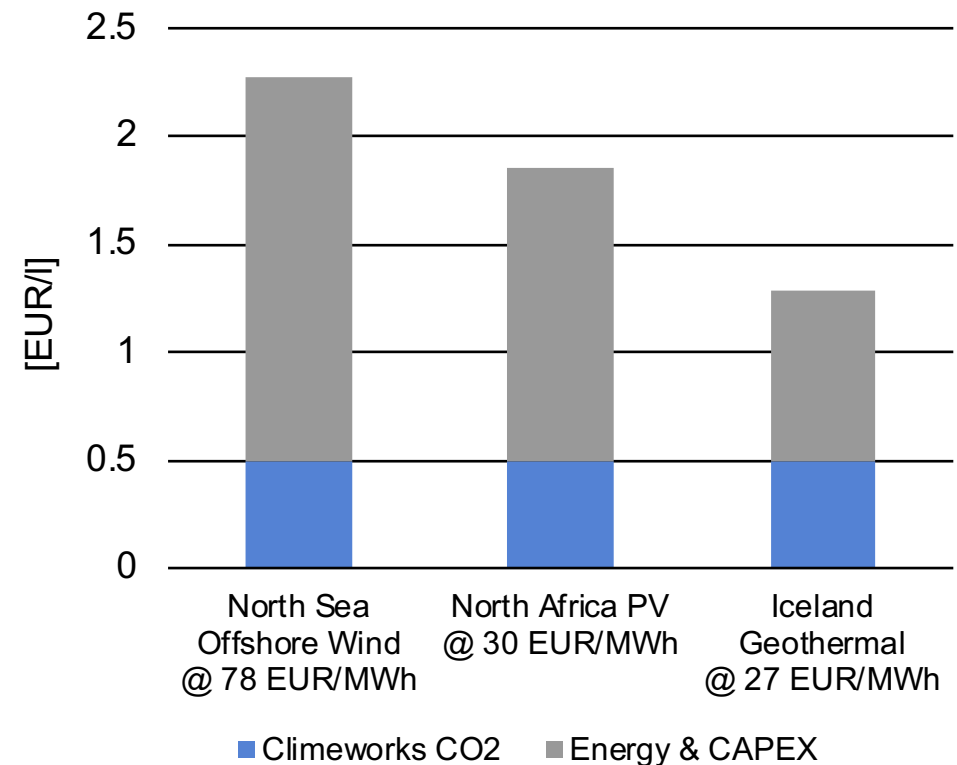


Costs depend predominantly on local electricity prices, CO₂ is present everywhere in the air.

Quelle Climeworks, 2019

PUBLIC

Renewable Synfuel Production Cost by 2025



Source: Agora (2018) The Future Cost of Electricity-Based Synthetic Fuels / Climeworks

Land Use of Bio and Synthetic Fuels

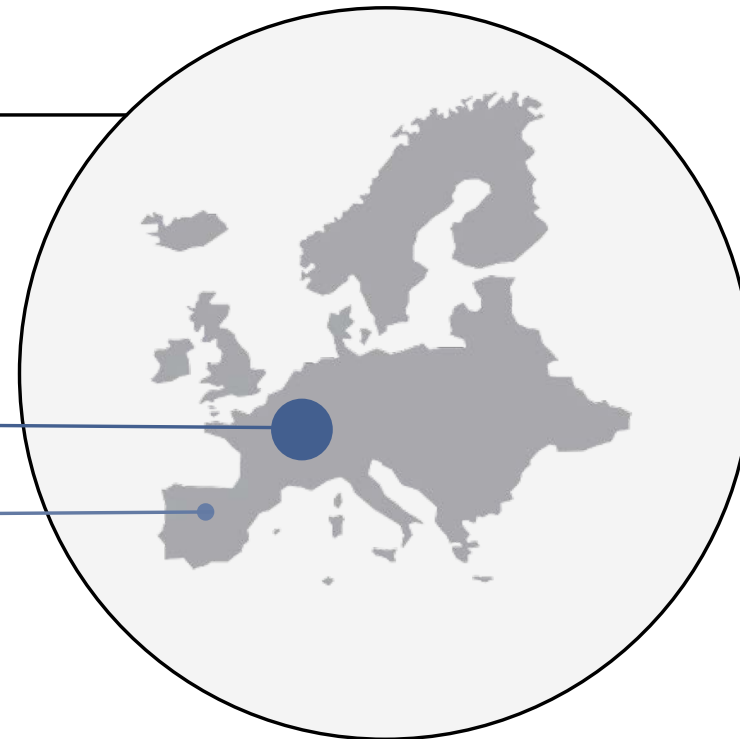


Surface area needed to meet the 2010 EU transportation energy demand (17,000 pJ/year)

Corn Biofuel
28'000'000 km²
of arable land
(yield assumption 18 g/ac/y)

Algae Biofuel
200'000 km²
of barren land
(yield assumption 2'500 g/ac/y)

Renewable Synfuels
14'200 km²
of barren land
(assumption: 1'900kWh/m²,
 $\eta_{PV} = 25\%$, $\eta_{PtX} = 70\%$)



Source Climeworks, 2019



Thank you for your attention!

pdf of the slides: lguzzella@ethz.ch