Energieträger für die CO_2-freie Mobilität: eine Einordnung

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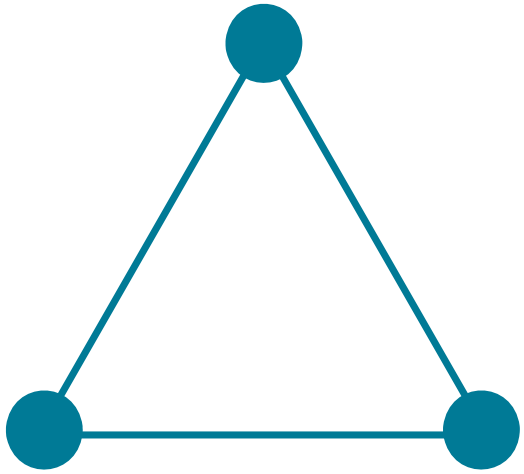
With contributions by G. Pareschi (ETH Zürich)

Worüber wollen wir heute sprechen?

- CO_2-Emissionen – wie viel trägt die Schweiz bei?
- Anteil der Mobilität am Energiesystem und Klimawirkung
- Zwei Wege zur “Dekarbonisierung” des Verkehrs
- E-Mobilität: wieviel Elektrizität braucht es? Aus welchen Quellen?
- Synthetische Treibstoffe: woher? Zu welchem Preis?

Energy and climate policy: the “Trilemma”

Net-Zero CO_2
(and minimization of other environmental impact)



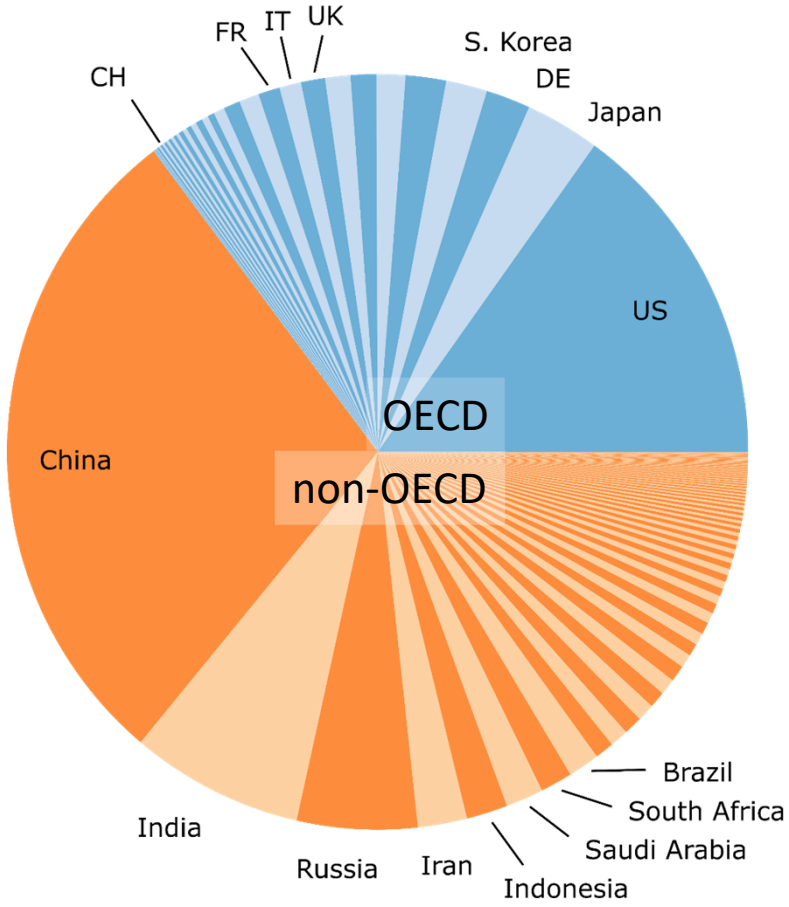
→ Partially conflicting goals
→ Optimization required

Security of Energy Supply
(Diversification, Share of imports)

Competitiveness
(of industry) / fair access to energy services

Alignment with international regulations /
currently: CH-energy expenditures **~4% of GDP**

Distribution of today's greenhouse gas emissions by country and remaining CO_2 budget



- Current global CO_2 emissions: 42 $GtCO_2$/y
- Remaining CO_2 budget for 1.5°: 380 $GtCO_2$
- Remaining CO_2 budget for 2.0°: 1100 $GtCO_2$

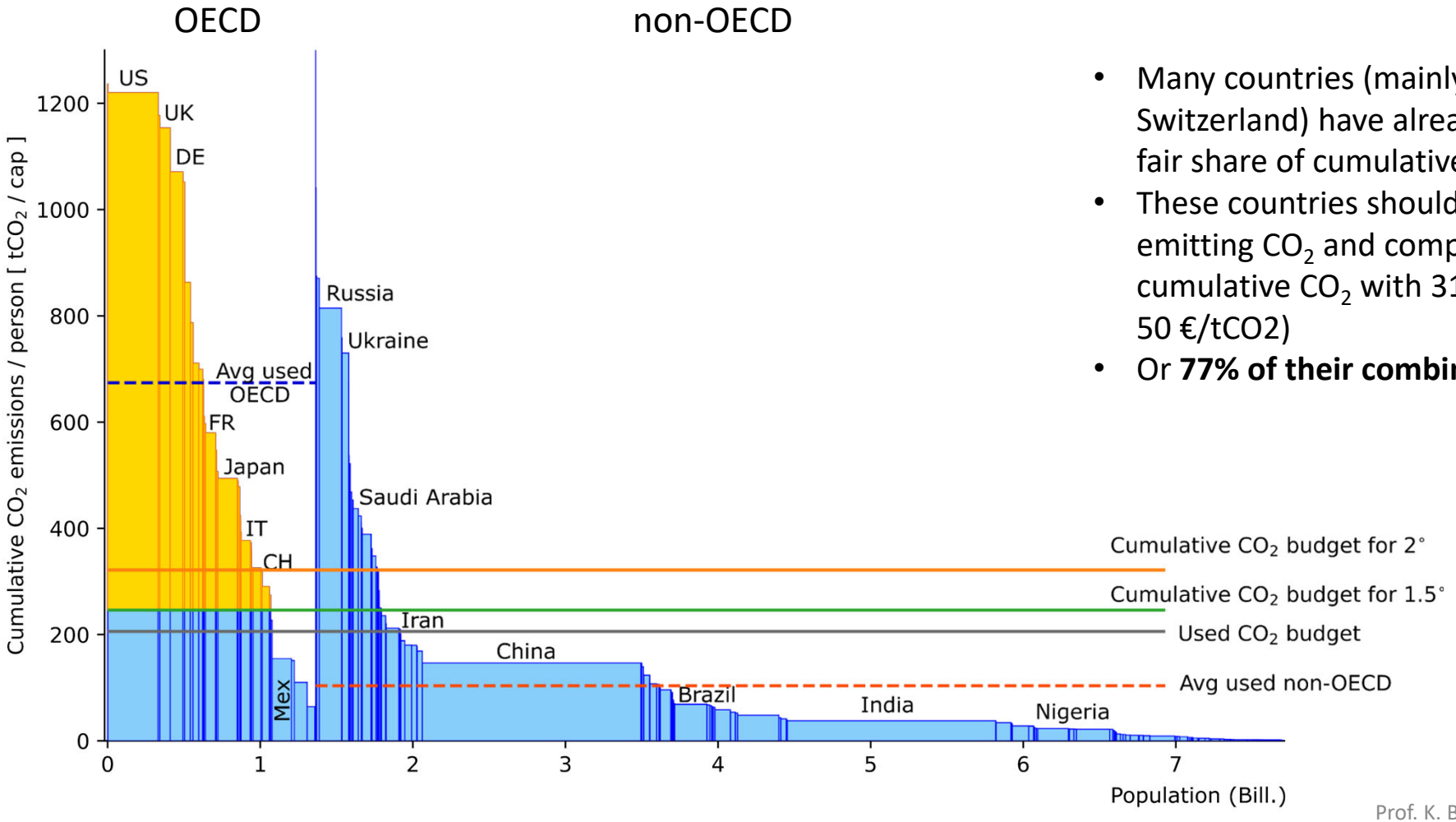
Therefore, assuming a linear decrease to Net-zero CO_2, we have:

- ~18 years to meet the **1.5°** target **(2040)**
- ~50 years to meet the **2.0°** target **(2070)**

Swiss Federal Council and the EU Green Deal have set a target of net-zero CO_2 for **2050**.

Sources: IEA 2019; IPCC AR5; IPCC SR1.5; aggregated by G. Pareschi

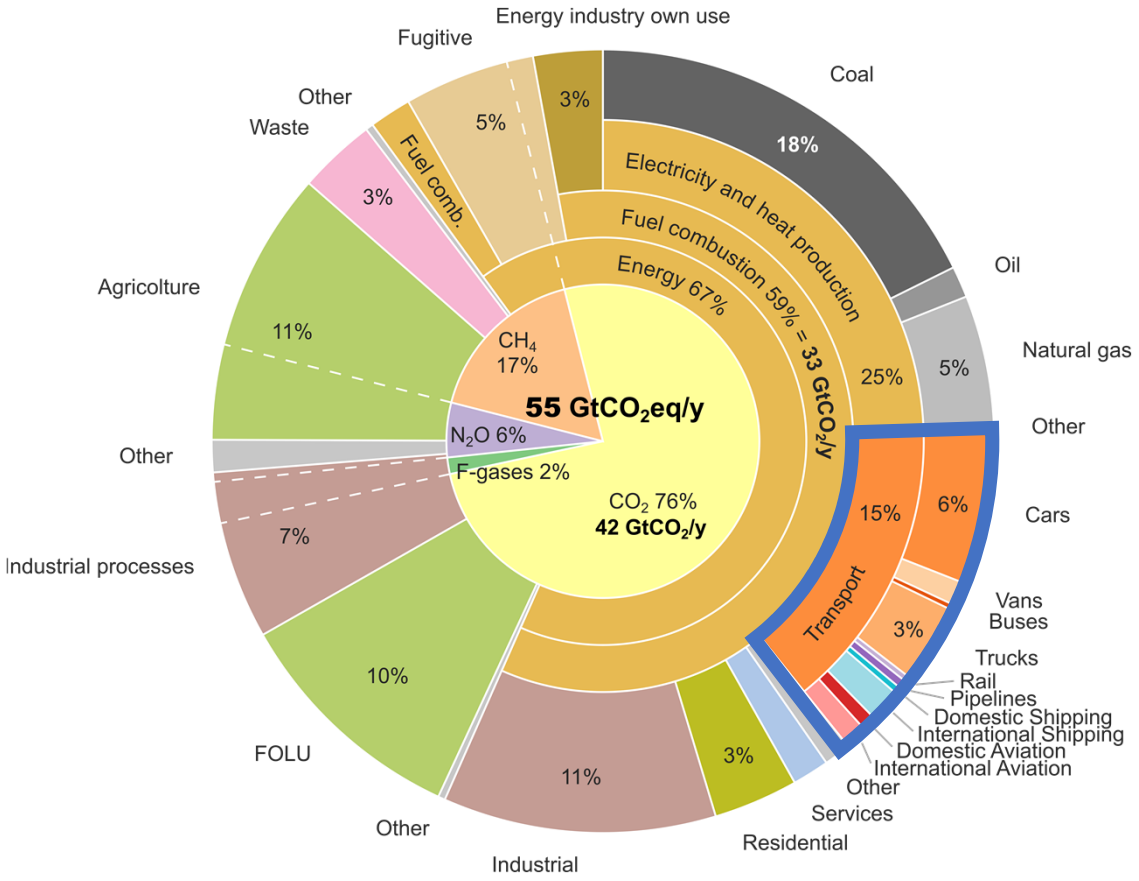
Historical cumulative emissions: the responsibility of early industrialized countries

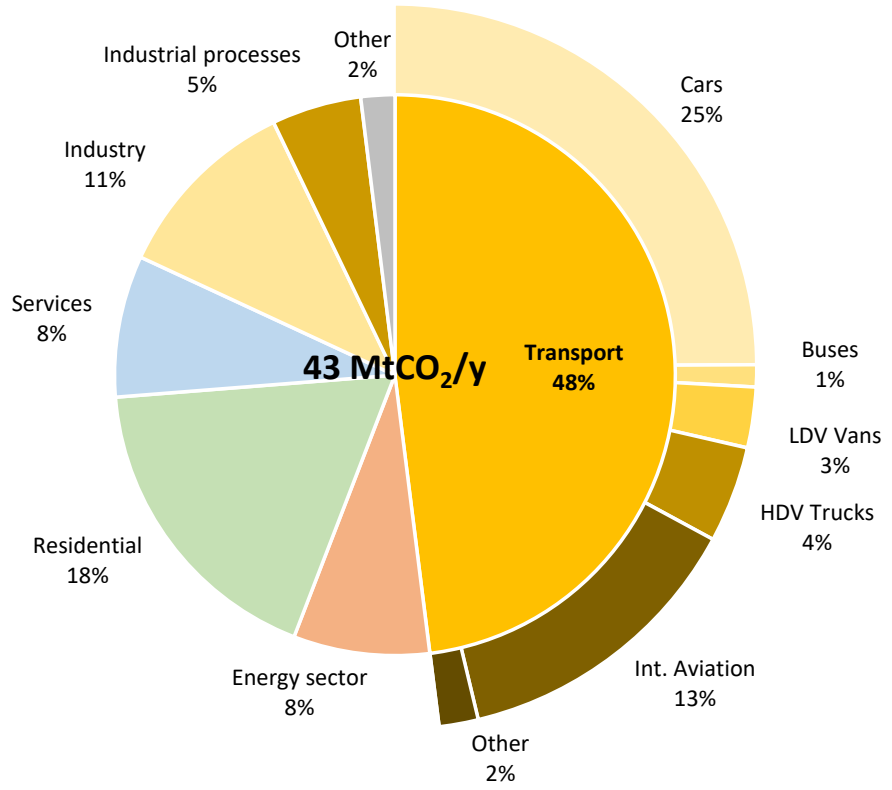


- Many countries (mainly OECD, incl. Switzerland) have already depleted their fair share of cumulative CO_2 emissions!
- These countries should immediately stop emitting CO_2 and compensate the excess cumulative CO_2 with 31 trill. € (assuming 50 €/tCO2)
- Or **77% of their combined GDP!**

Sources: Gütschow, J.; Günther, A.; Pflüger, M. (2021): The PRIMAP-hist national historical emissions time series (1750-2019). v2.3.1. zenodo. https://doi.org/10.5281/zenodo.5494497

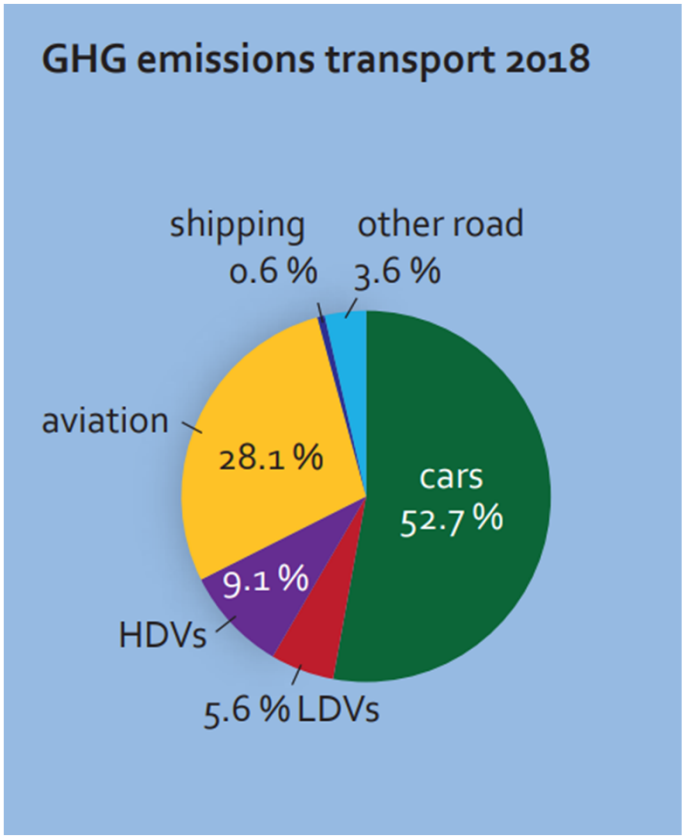
Global (←) and Swiss (→) GHG emissions breakdown





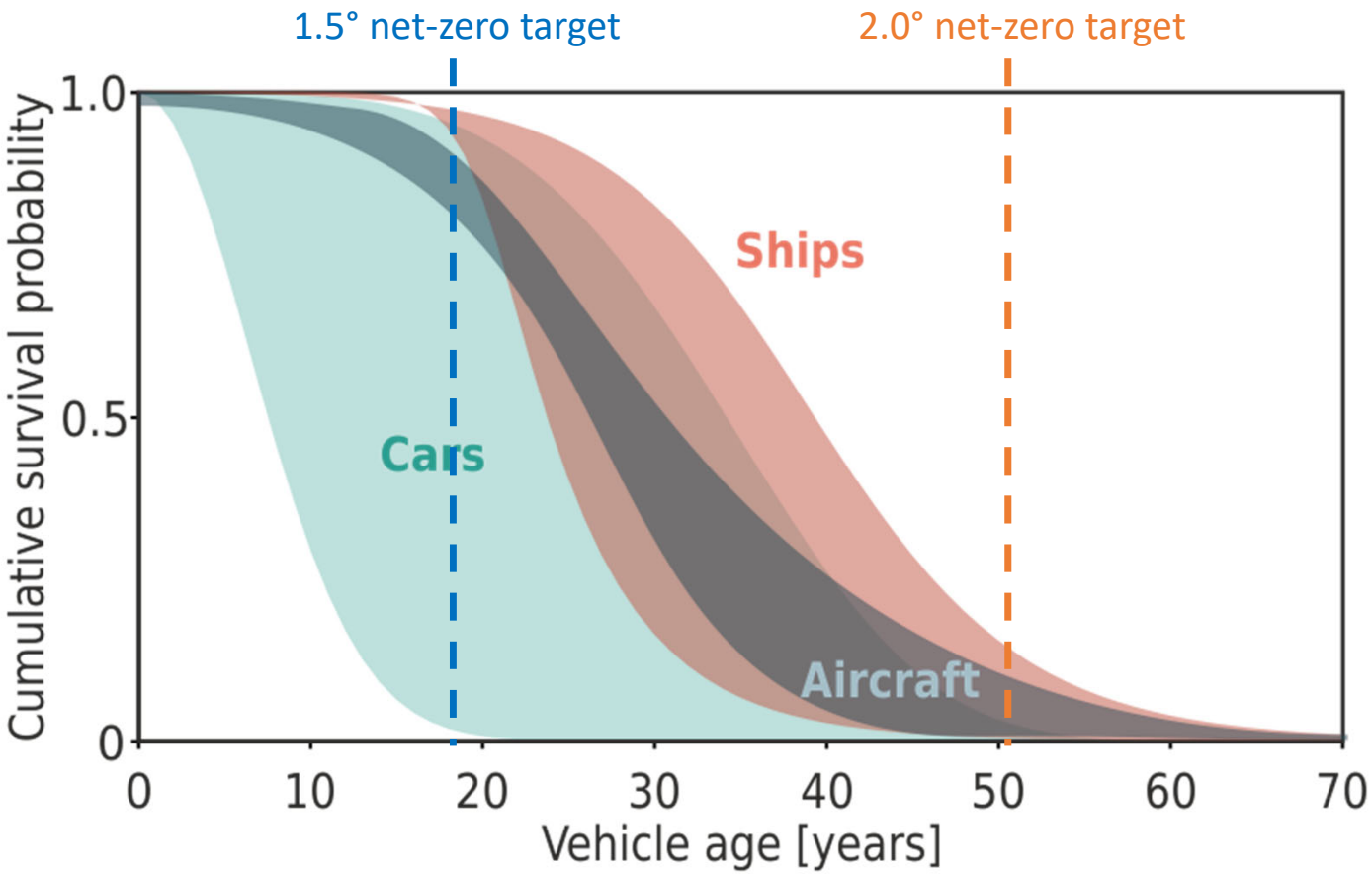
Sources: BAFU, Greenhouse gas emissions of Switzerland 1990-2019

Current Share and Future Growth of Mobility Sectors



Distribution and evolution of greenhouse gas (GHG) emissions from the transport sector in Switzerland (FOEN 2020a) as well as future demand projections (ARE 2016; Intraplan 2015).

If we have 20-50 years, why is immediate action imperative?



In addition:

- Power plants → 20-50 years
- Buildings → 30-100 years
- Industrial processes → > 20 years
- Roads, Grids, Refineries → 50-100 years

- Huge need for investments in infrastructure!
- Invest in decarbonizing incumbent assets!

Data for cars from Held et al. (2021): *European Transport Research Review*, vol. 13, art. 9
Data for ships from Held et al. (2021): *7th Internat. Symposium on Ship Operations, Management, & Economics*
Data for aircraft from Dray (2013): *Journal of Air Transport Management,* vol. 28, pp. 62-69

Two kinds of energy carriers for mobility:

- **Renewable electricity for:**
  - Cars
  - Light-duty freight transport
  - Urban buses
  - 2/3 wheelers
  - Rail transport

- **Renewable (synthetic) fuels for:**
  - Heavy-duty freight transport
  - Aviation
  - (Long-haul shipping)

Electricity Balance today and in 2050

Electricity Consumption

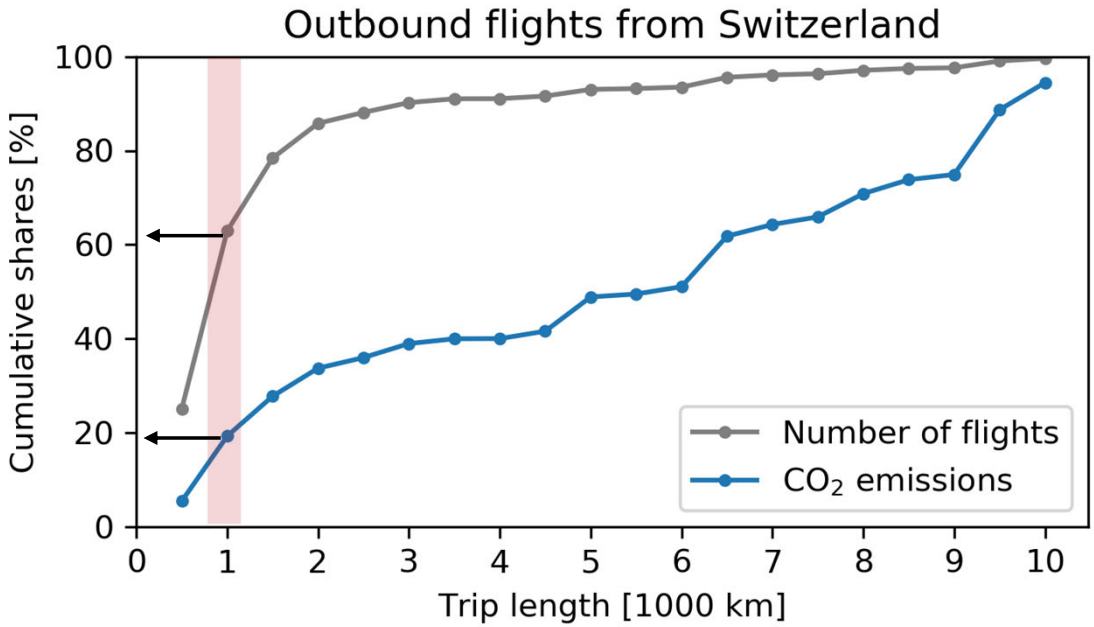
Electricity Generation

However, the situation in Winter requires imports in the order of **9 TWh** (compared to today's 5 TWh)

Quelle: EP2050+, Szenario ZERO Basis

Several energy sectors cannot be directly electrified

Example of long-haul aviation



- Estimates indicate that with a battery-pack energy density of 800 Wh/kg (expected around 2050), 1’000 km of flight could be covered by all-electric aircrafts.
- However, outbound flights shorter than 1’000 km correspond to only **19%** of total Swiss CO_2 emissions from aviation.

→ Similar challenges for shipping, heavy-duty trucks and some industrial processes

Source:

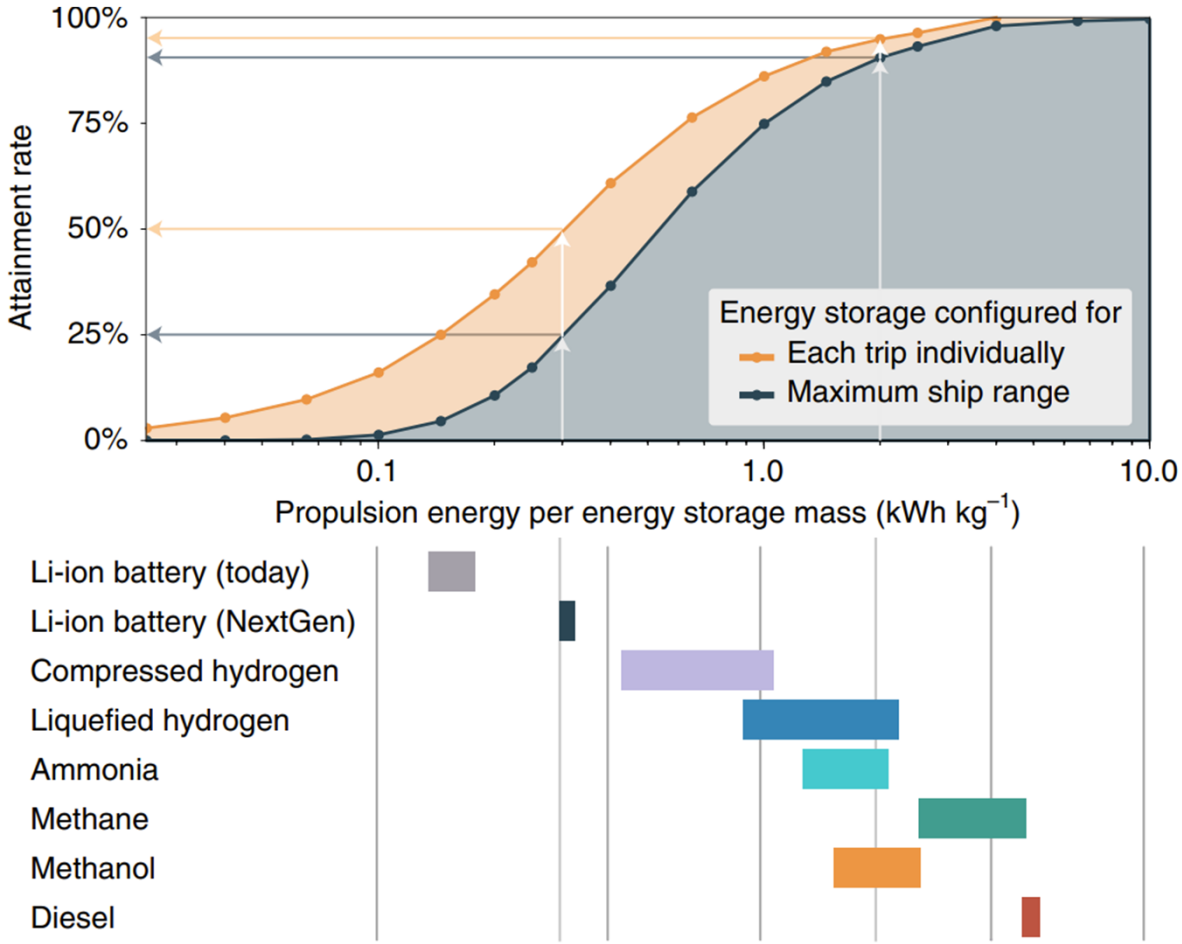
- Own calculation based on the methodology of: Seymour K., Held M., Georges G., Boulouchos K. (2020): "Fuel Estimation in Air Transportation: Modeling global fuel consumption for commercial aviation” in Transportation Research Part D: Transport and Environment, DOI: 10.1016/j.trd.2020.102528
- Schäfer A., et al. (2019): „Technological, economic and environmental prospects of all-electric aircraft” in Nature Energy, vol.4 (2), pp. 160-166

Applicability of energy carriers to bulk carriers ship

Attainment rate = share of ton-nautical-miles (tnm) that can be covered by each energy carrier, depending on:

- Mass-specific energy storage capacity
- Ship propulsion system

Includes all voyages up to 16’000 nautical miles



Source: Stolz at al. (2022). Techno-economic analysis of renewable fuels for ships carrying bulk cargo in Europe. *Nature Energy*

We anticipate that in the future Switzerland will need:

28 TWh_{chem} of e-fuels **(–66% vs current transport fossil fuels)**, to be imported:

- 22 $TWh_{kerosene}$ for aviation*
- 6 TWh_{H2} for heavy-duty freight transport*

which require:

$$22 \cdot 2.7^{\dagger} + 6 \cdot 1.8^{\dagger} = \mathbf{70\ TWh_{electricity}}$$

†Today's electricity-to-fuel factor lies between **1.8** (hydrogen) and **2.7** (liquid hydrocarbons).

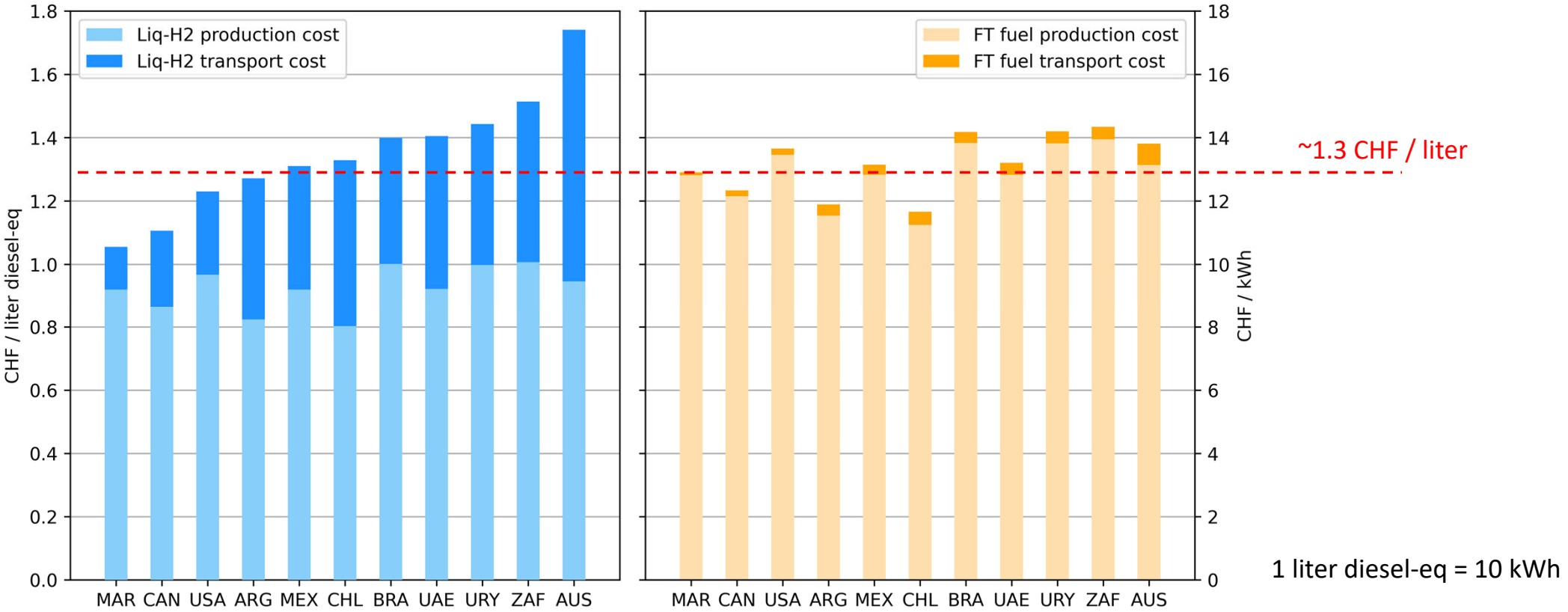
*Both of which may change in the future because of 1) increase in demand and 2) improved efficiency (but with the former stronger than the latter)

Source: Stolz at al. (2022). Techno-economic analysis of renewable fuels for ships carrying bulk cargo in Europe. *Nature Energy*

What would it take to produce 70 TWh of electricity? (just for e-fuels for transportation!)

	Full-load hours	Peak capacity	Surface area km x km	Surface area % of Switzerland
PV in Switzerland	1’100	**64 GW**	32 x 32	2.5%
PV in Middle East	2’500	**28 GW**	16 x 16	0.6%
Off-shore Wind EU	4’000	**17 GW**	57 x 57	7.9%
On-shore Wind Patagonia	5’300	**13 GW**	40 x 40	3.9%
Nuclear	7’500	**9 GW**	Virtually 0	Virtually 0

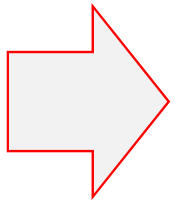
Projected costs in 2050 for production and transportation of e-fuels



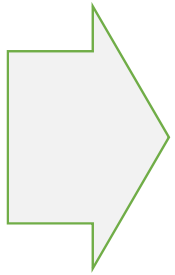
Source: PtX-Atlas: Weltweite Potenziale für die Erzeugung von grünem Wasserstoff und klimaneutralen synthetischen Kraft- und Brennstoffen

A fair cost-comparison of fuel imports to Switzerland

(2017 CHF)	**2020**	**2050**
Avg. fuel cost at wholesale	~ 0.48 CHF / l	~ 1.3 CHF / l
Transport fuel imports	82 TWh	28 TWh
Total expenditure for importing chemical fuels	~ 4 bill. CHF	~ 3.6 bill. CHF
GDP	713 bill. CHF	969 bill. CHF
% of GDP	~ 0.6 %	~ 0.4 %



Individual hard-to-decarbonize sectors may suffer

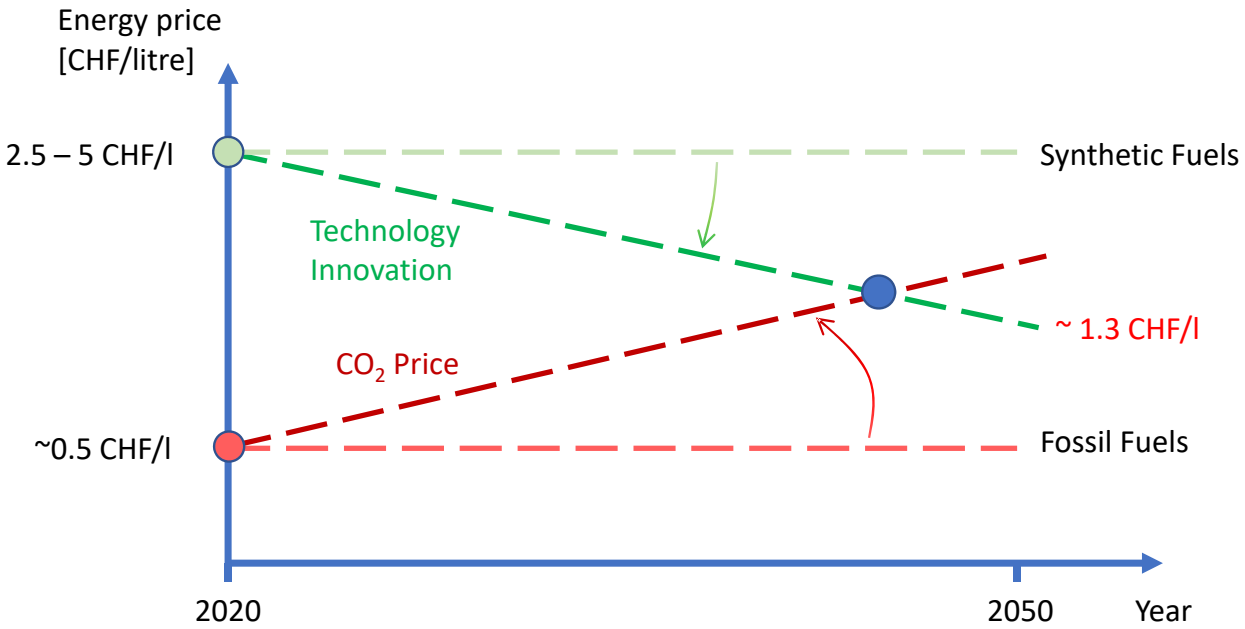


Macroeconomically affordable

But keep in mind that hard-to-decarbonize sectors will be hit anyhow by CO_2 prices, if they remain based on fossil fuels.

→ Let's start investing in e-fuels immediately to accelerate learning and reach cost parity!

CO_2-pricing & technology innovation - We need both!



Assuming that fossil fuel price will remain around 0.5 CHF/l, "Net-zero" CO_2 e-fuels will become competitive at CO_2 prices of ~300 CHF/tCO_2
Today's CO_2 price ~= 60 CHF/tCO_2

[1]IEA (2021), Is carbon capture too expensive?, IEA, Paris https://www.iea.org/commentaries/is-carbon-capture-too-expensive

Schlussfolgerungen & Ausblick

- Dekarbonisierung des Energiesystems ist dringend nötig.
- Mobilität stellt in der Schweiz diesbezüglich die grösste Herausforderung dar.
- Autos und Lieferwagen/Stadtbusse können durch inländische Stromproduktion bedient werden, aber Importe von etwa 10 TWh werden im Winterhalbjahr erforderlich sein (2050).
- Langstreckenverkehr ist Schlüsselfaktor (Luftfahrt, LKW) – Bedarf an neuer Infrastruktur und sehr hohen Investitionen. Importe von erneuerbaren Treibstoffen werden in 2050 etwa 35% der heutige Treibstoffimporte betragen.
- Geschätzte Gesamtkosten für erneuerbare Treibstoffimporte in 2050 etwa gleich hoch wie heute für fossile bei einem Anteil am BIP von 0.4% vs 0.6% heute.
- Synergien zwischen Innovation (Technologie, Geschäftsmodelle) und einer kohärenten Politik sind «match-entscheidend».

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ETH zürich

LAV

Danke schön

If Switzerland requires up to 28 TWh of "Zero"-CO_2 e-fuels, out of 70 TWh of electricity, can the entire World afford a similar path to sustainability?

Population in 2050

~10 mill.

~10 bill.

Assume similar development, i.e. similar GDP/cap and TWh/GDP

E-fuel end renewable electricity demand in 2050

28 $TWh_{e\text{-}fuels}$
70 TWh_{el}

28'000 $TWh_{e\text{-}fuels}$
70'000 TWh_{el}
(today = 23'000 TWh_{el})

The theoretical global renewable electricity potential is 120 mill. TWh_{el}[1]
The technical PV electricity potential is 2.5 – 7 mill. TWh_{el}[2]
The estimated potential for e-fuels (FT) lies between 57'000 – 69'000 $TWh_{e\text{-}fuels}$[3], with at least 20'000 TWh cheaper than 1.4 €/l.

[1]Assuming 20% of the net solar radiation reaching the Earth's surface is convertible to electricity (= 70'000 TW · 8760 h · 0.2).
[2]Krewitt 2009 and G. Pareschi analyses based on "ESMAP. 2020. Global Photovoltaic Power Potential by Country. Washington, DC: World Bank".
[3]Fraunhofer IEE 2021. PtX-Atlas: Weltweite Potenziale für die Erzeugung von grünem Wasserstoff und klimaneutralen synthetischen Kraft- und Brennstoffen. Numbers for 2050

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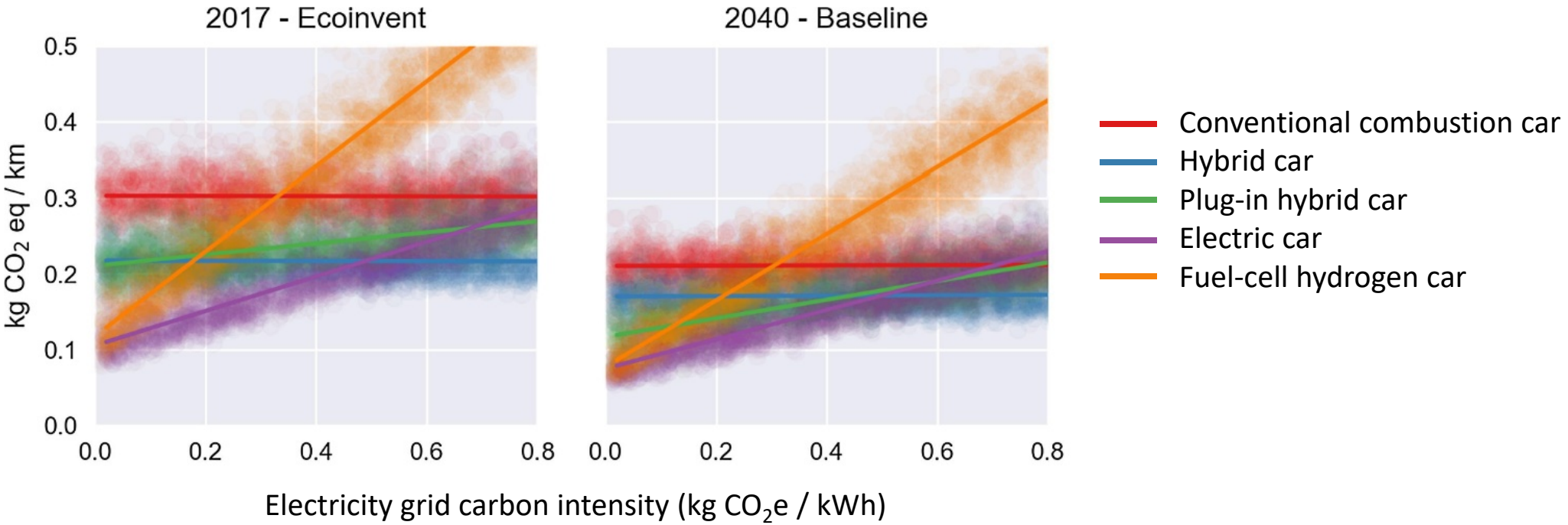
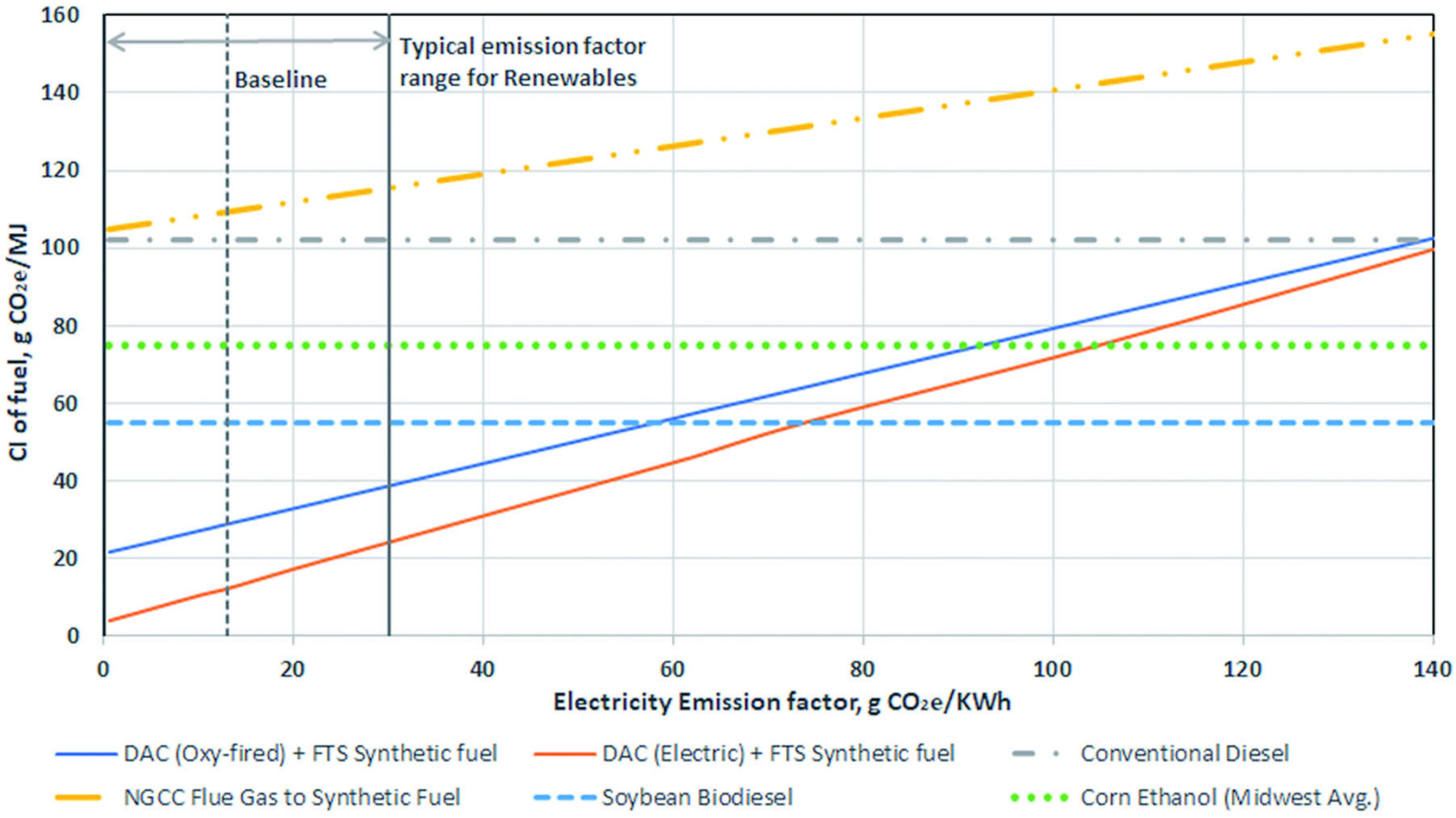
Climate effect of different car propulsion technologies



LCA-based climate impact of -fuels production



Sources: Liu et al. (2020). Sustainable Energy & Fuels