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Energieträger für die Mobilität der Zukunft: Dekarbonisierung, Versorgungssicherheit und Kosten

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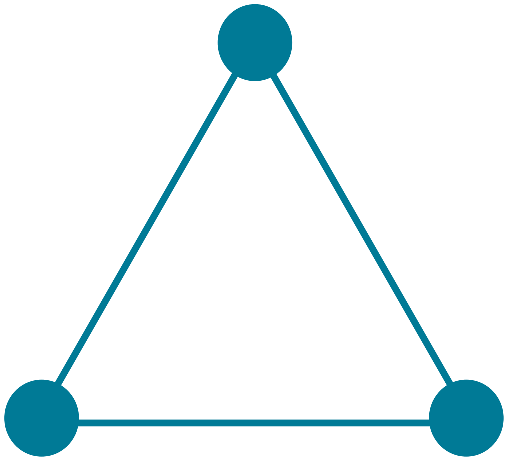
With contributions by G. Pareschi (ETH Zürich)

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)



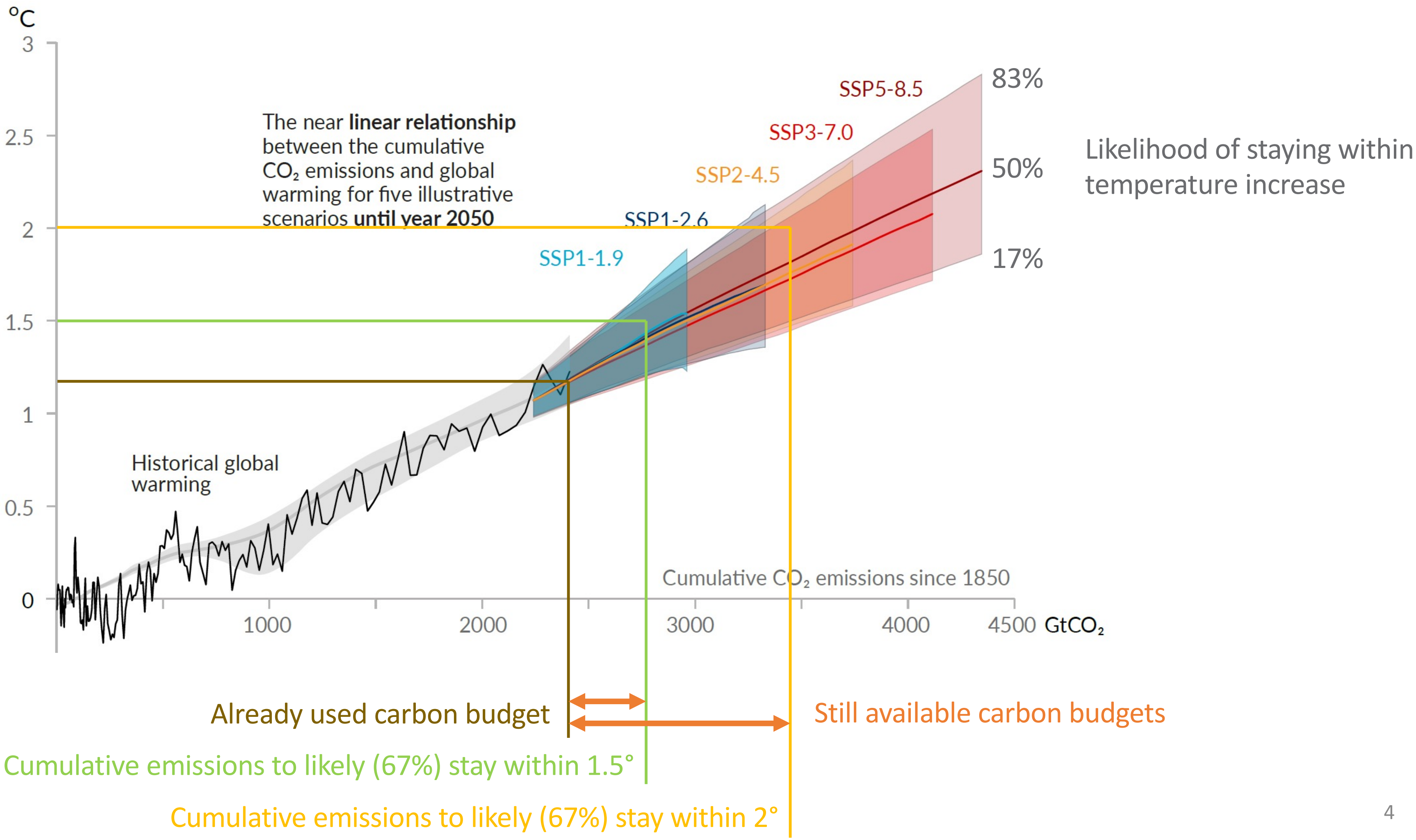
Security of Energy Supply
(Diversification, Share of imports)

Competitiveness
(of industry) / fair access to energy services

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

→ Partially conflicting goals
→ Optimization required

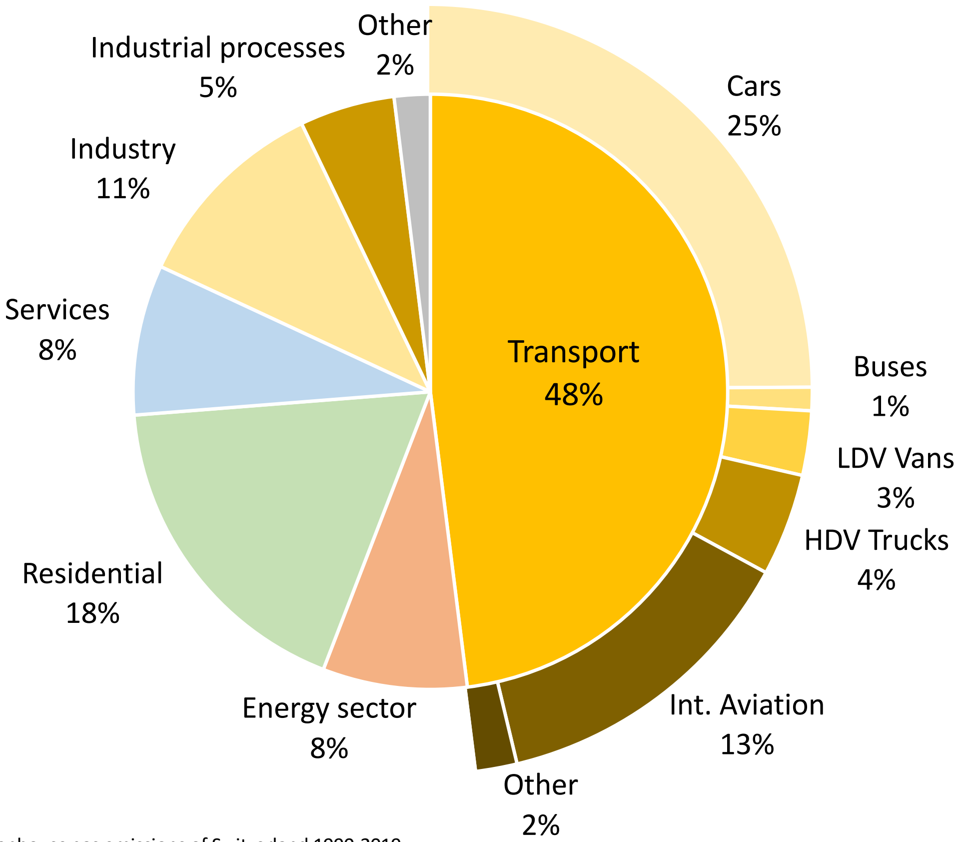
Every tonne of CO_2 adds to global warming



Sources: IPCC AR6 WG1

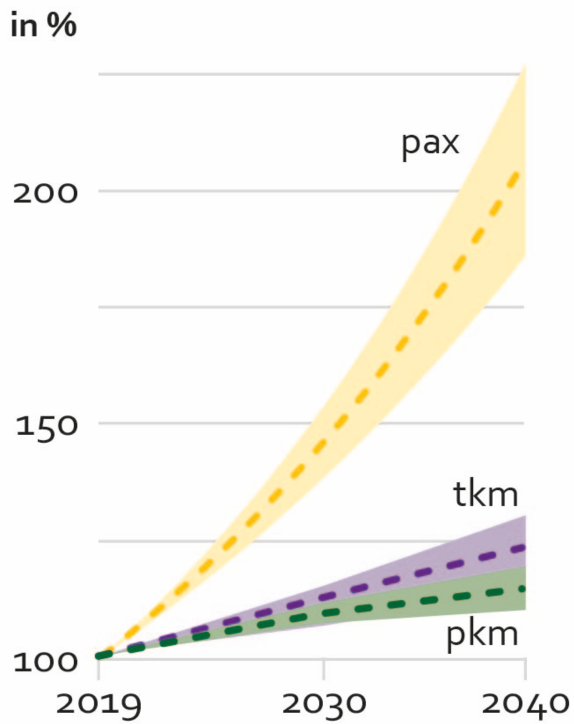
Relevance of Transportation for the Swiss CO_2 Emissions

Total 2019: 43 MtCO$_2$/y



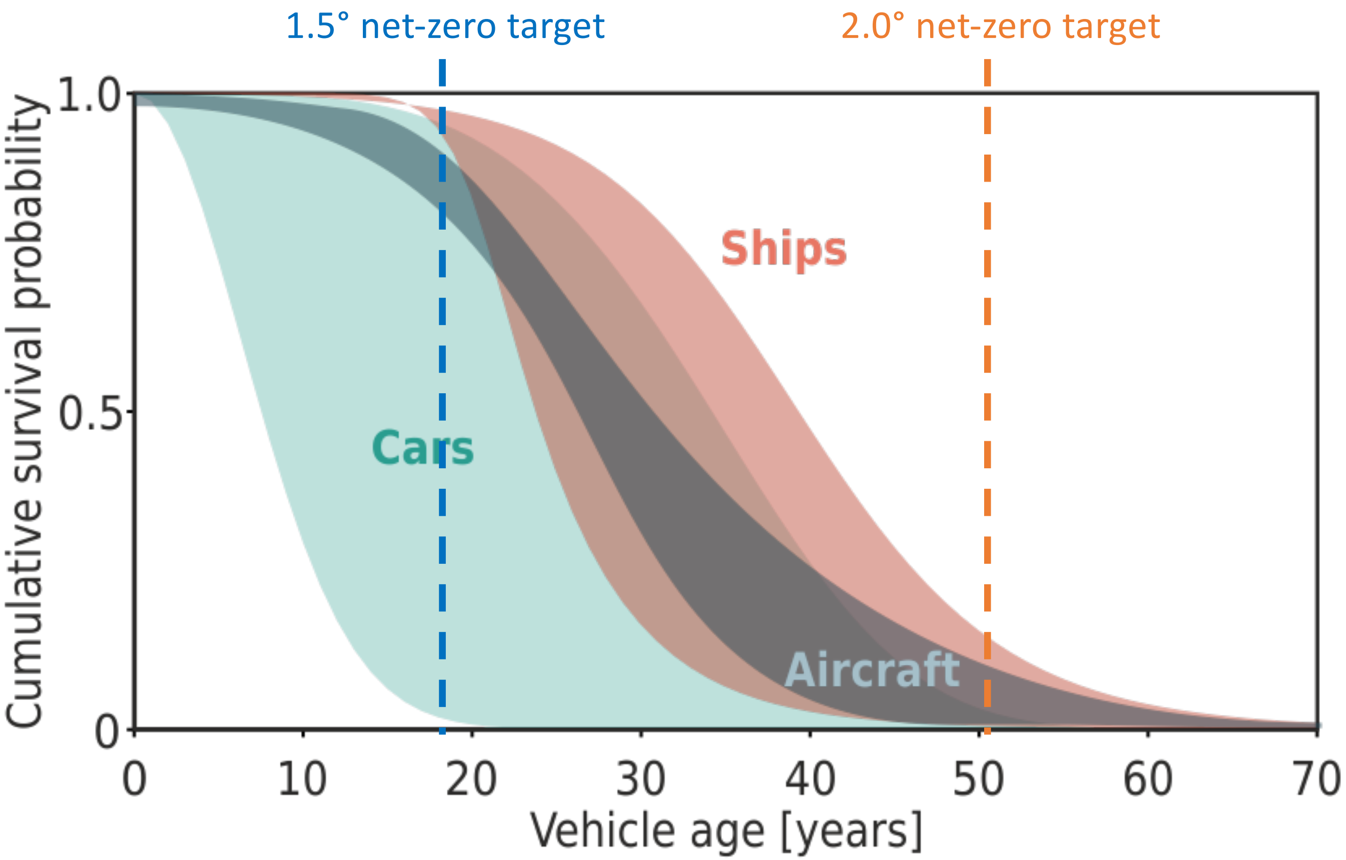
Sources: BAFU, Greenhouse gas emissions of Switzerland 1990-2019

Example of expected increase in transportation service demand:



sources: ARE 2016, Intraplan 2015

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



In addition:

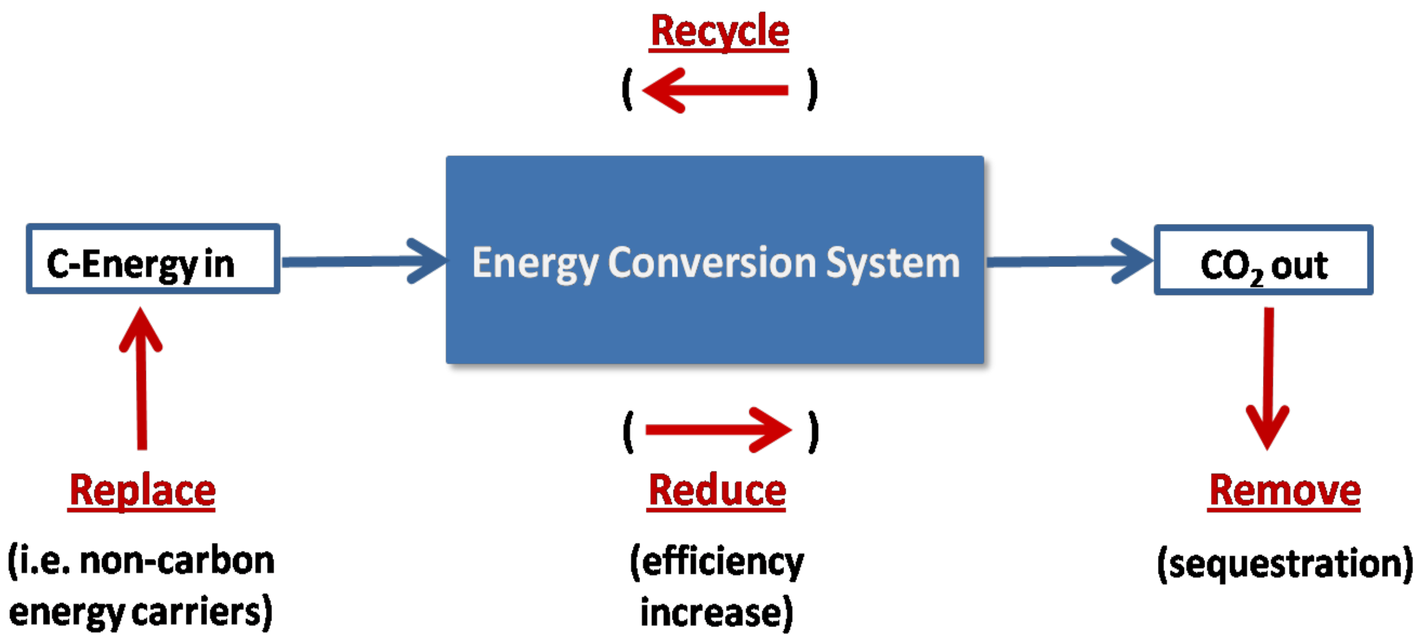
- Power plants → 20-50 years
- Buildings → 30-100 years
- Industrial processes → > 20 years
- Roads, Grids, Refineries → 50-100 years

- 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

How can we reduce CO_2-emissions?

→ (the four **R**'s – strategy)



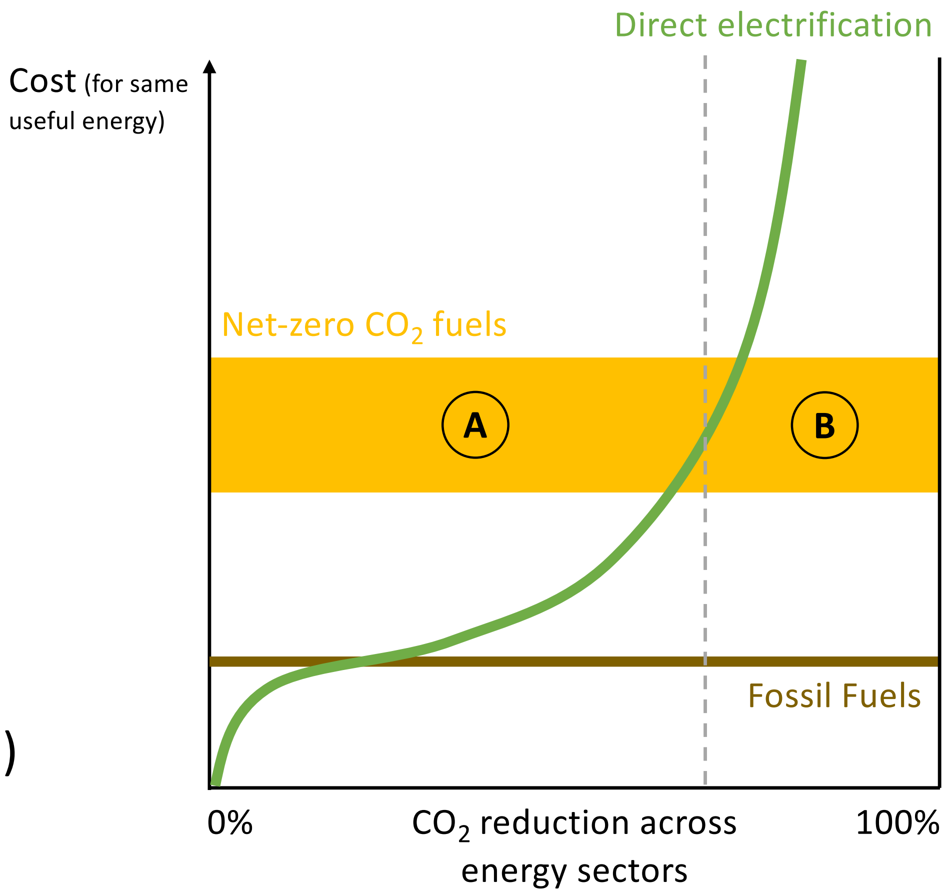
Two complementary “Replace” strategies

A. Directly electrify what is possible:

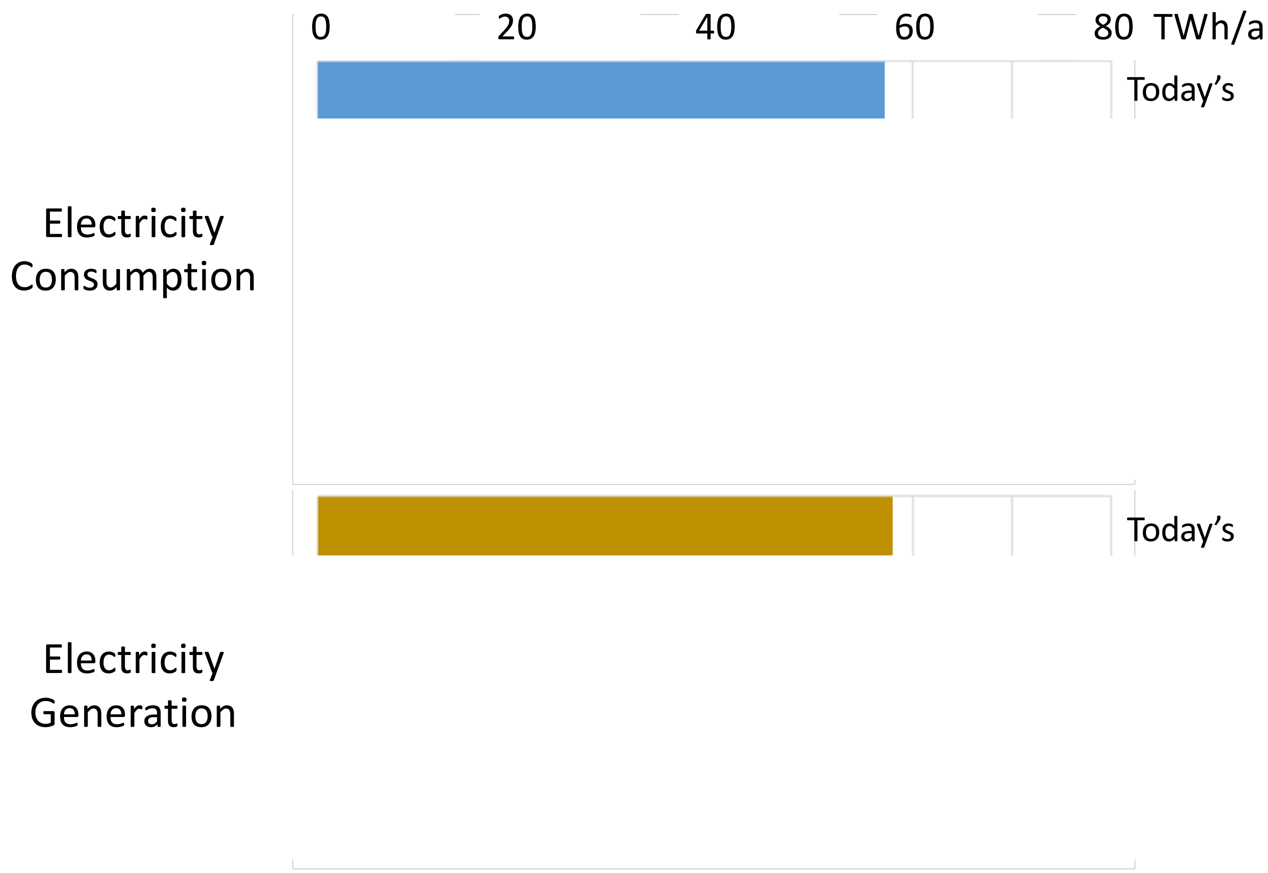
- Cars
- Light-duty road
- Low-temperature heating (heat pumps)

B. Use “Net-zero” CO_2 chemical energy carriers elsewhere:

- Heavy-duty road
- Aviation
- Seasonal electricity storage (?)
- High-temperature industrial process heat (?)
- (Shipping)



Electricity Balance today and in 2050



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

Quelle: EP2050+, Szenario ZERO Basis

We anticipate that in the future we will need in addition about:

28 TWh_{chem} of e-fuels **(–80% vs total fossil fuels currently)**, to be imported:

- 21 $TWh_{kerosene}$ for aviation*
- 7 TWh_{H2} for heavy-duty freight transport*

which require:

$$21 \cdot 2.7^{\dagger} + 7 \cdot 1.8^{\dagger} = \mathbf{70\ TWh_{electricity}}$$

For comparison the domestic Swiss electricity demand in 2050 will be in the same order of 70 TWh.

*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)

†Today's electricity-to-fuel factor lies between 1.8 (hydrogen) and 2.7 (liquid hydrocarbons). Source: B. Stolz, M. Held (2021) accepted in *Nature Energy.*

What would we need to produce 70 TWh of electricity?

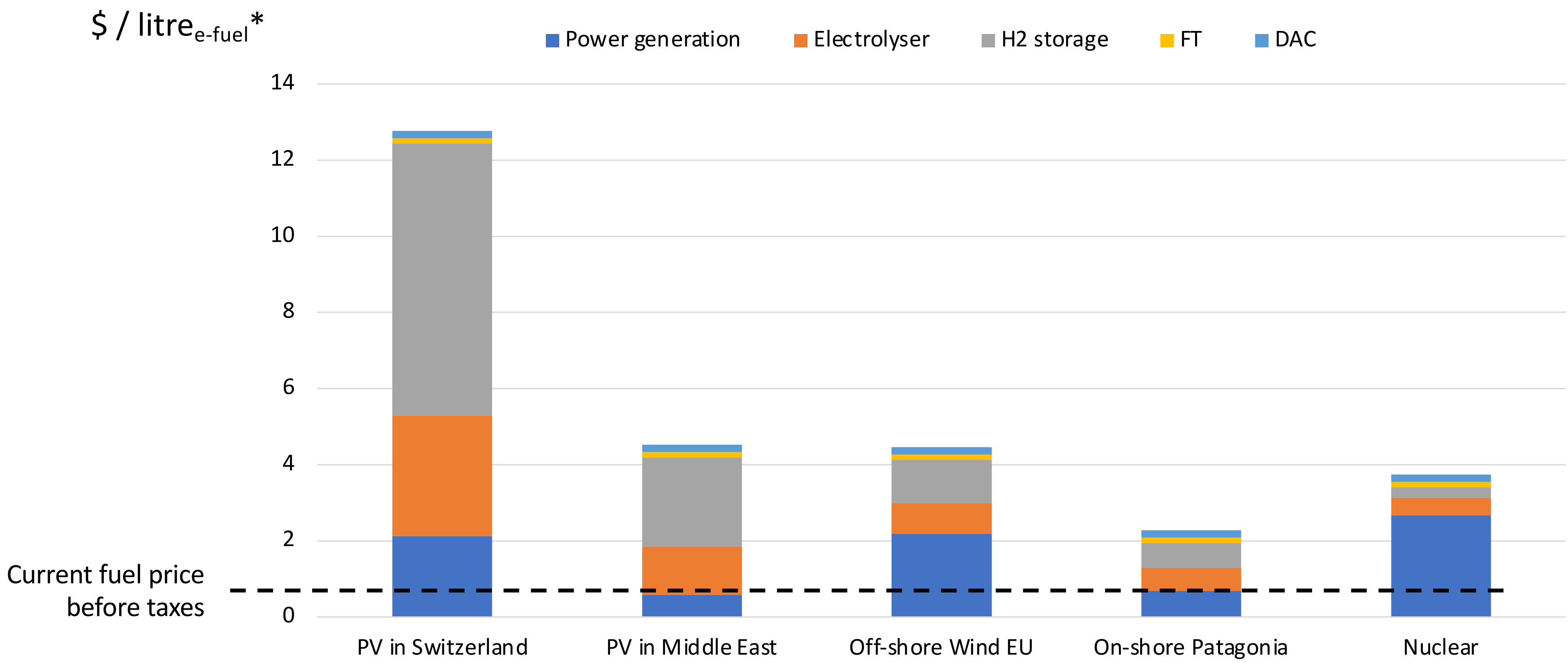
	Full-load hours	Peak capacity	CAPEX $ / kW$_{peak}$	Lifetime years	LCOE $ / kWh	Annualized costs power generation bill. $	Annualized costs electricity to e-fuel* bill. $	Total annualized costs bill. $
PV in Switzerland	1'000	**70 GW**	1'100	25	0.09	6.0	29.8	**35.8**
PV in Middle East	2'500	**28 GW**	750	25	0.02	1.6	11.0	**12.6**
Off-shore Wind EU	4'000	**18 GW**	3'200	25	0.09	6.1	6.4	**12.5**
On-shore Wind Patagonia	5'300	**13 GW**	1'500	25	0.03	1.9	4.4	**6.3**
Nuclear	7'000	**10 GW**	7'000	50	0.11	7.5	3.0	**10.5**

Compare to current ~6 bill. CHF spent for importing transportation fuel!

*Excluding costs for transport

Preliminary results G. Pareschi (LAV ETHZ)

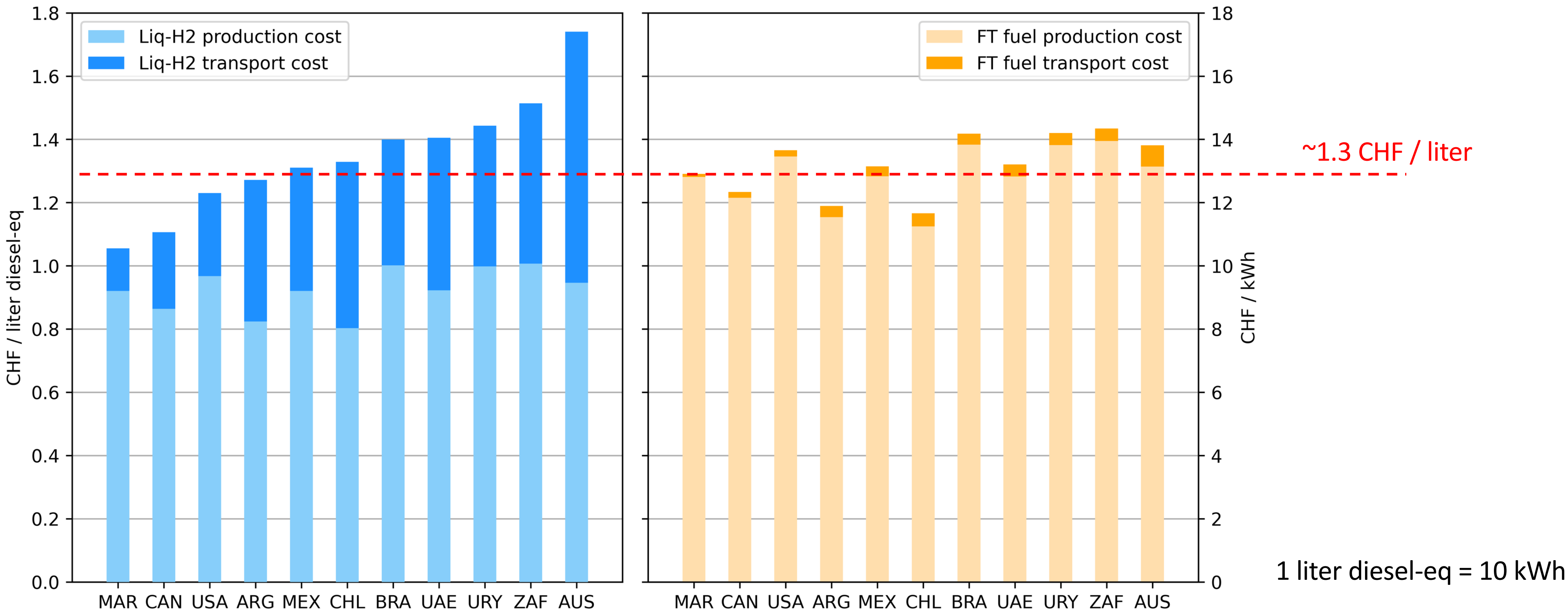
Current costs of generating e-fuels via different paths



*Excluding costs for transport

Preliminary results G. Pareschi (LAV ETHZ)

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 transport fuel imports to Switzerland

(2017 CHF)	2020	2050
Avg. fuel cost at wholesale	~ 0.5 CHF / l	~ 1.3 CHF / l
Transport fuel imports	82 TWh	28 TWh*
Expenditure for importing chemical fuels	~ 4.1 bill. CHF	~ 3.6 bill. CHF
GDP	713 bill. CHF	969 bill. CHF
% of GDP	~ 0.6 %	~ 0.4 %

Individual hard-to-decarbonize transport modes would suffer

Macroeconomically affordable

*However, passenger cars and LDV would consume ~17 TWh of additional electricity, which – with a wholesale market price of 0.05 CHF/kWh – would make 0.85 bill. CHF. That makes a total of 4.45 bill. CHF which is less than 0.5% of GDP.

→ 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!

Schlussfolgerungen & Ausblick

- Dekarbonisierung des Energiesystems ist dringend nötig.
- Mobilität stellt in der Schweiz diesbezüglich die grösste Herausforderung dar.
- Autos und Lieferwagen/Busse können durch inländische Stromproduktion bedient werden, aber Importe von etwa 10 TWh werden im Winterhalbjahr erforderlich sein (2050).
- Langstreckenverkehr ist Schlüsselfaktor – Bedarf an neuer Infrastruktur und sehr hohen Investitionen. Importe von erneuerbaren Treibstoffen werden (in 2050) etwa 20% der gesamten heutigen fossilen Importe bzw. 35% der Treibstoffimporte betragen.
- Politik und Wirtschaft müssen sich früh genug und schnell genug um Finanzierung diese Investitionen und Kooperationsabkommen mit verschiedenen Ländern (Diversifizierung) sorgen.

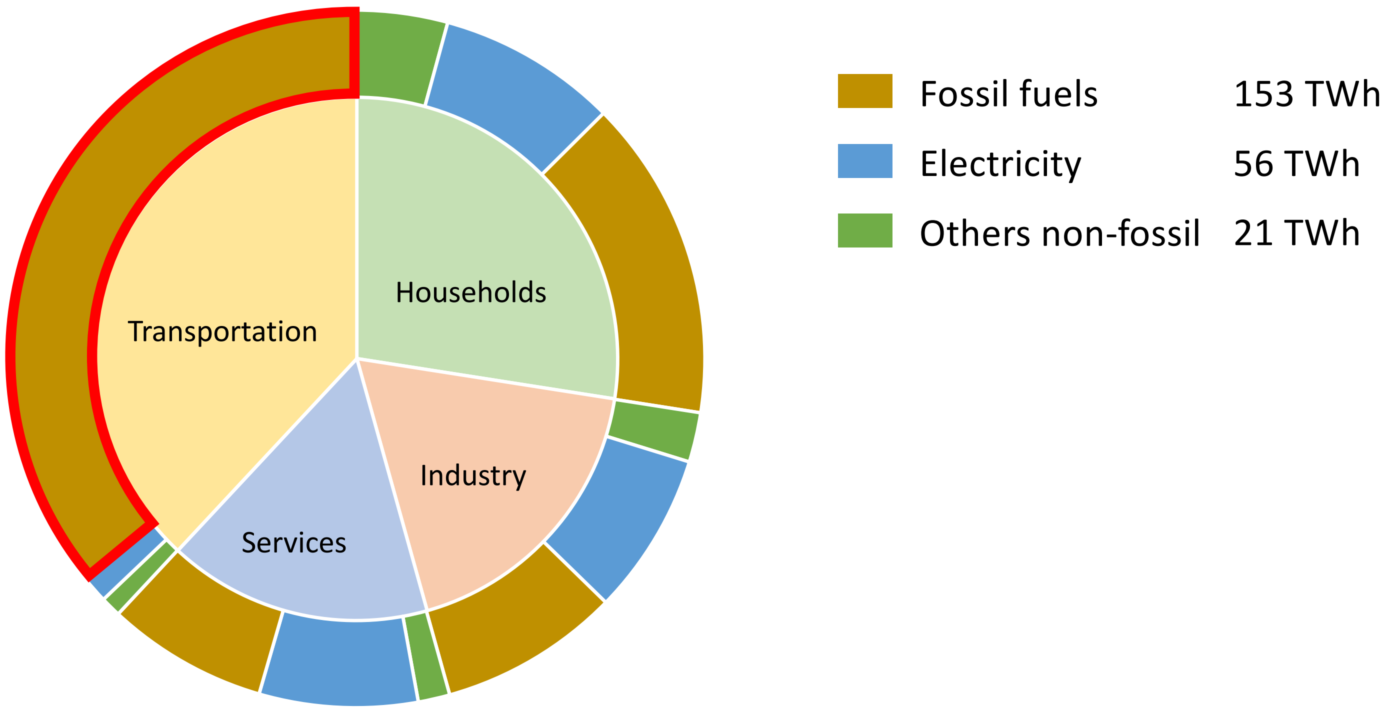

Danke schön

Relevance of Transportation for Final Energy Demand and CO_2 Emissions

Households	63 TWh
Industry	42 TWh
Services	37 TWh
Transportation	87 TWh

Or 48% of all domestic CO_2 emissions!!

Total: 229 TWh / y

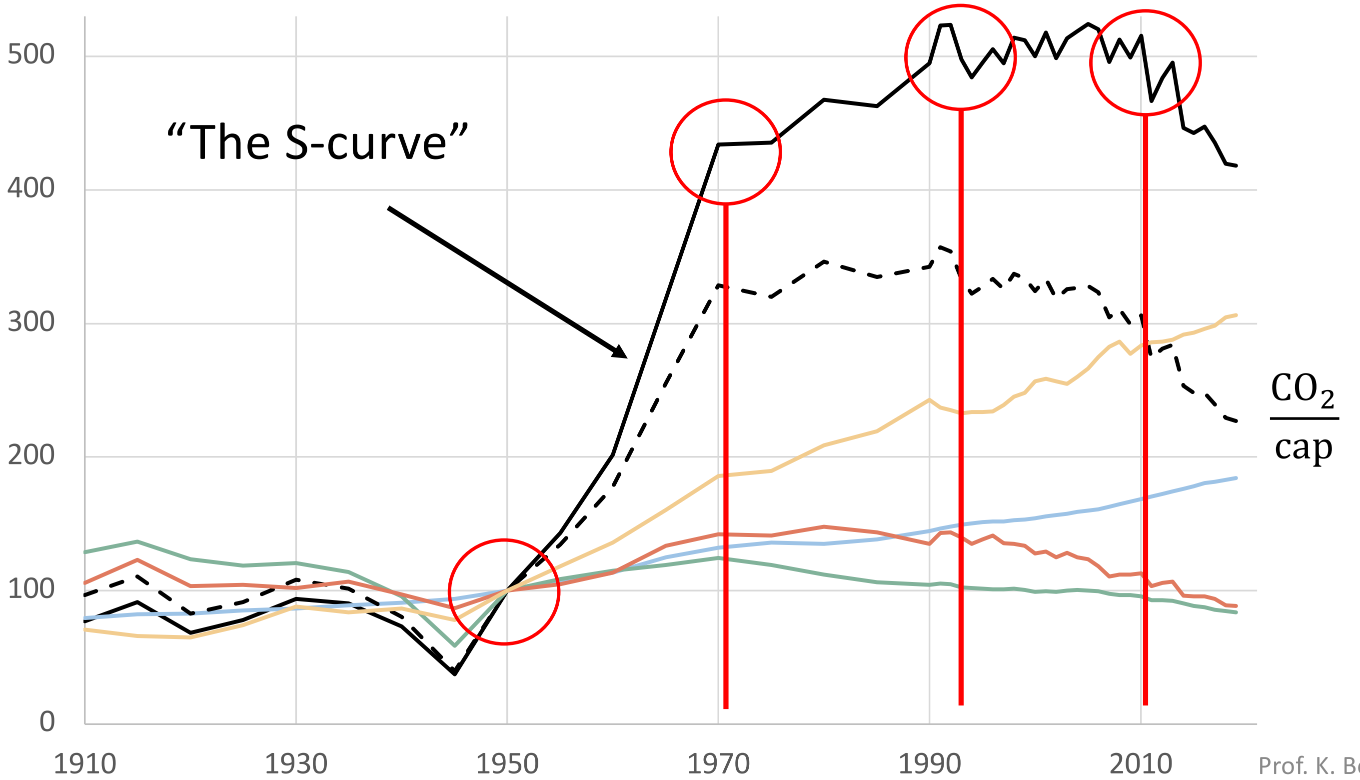


Sources: BFE, Schweizerische Gesamtenergiestatistik 2019

Drivers behind CO_2 growth… and CO_2 reduction

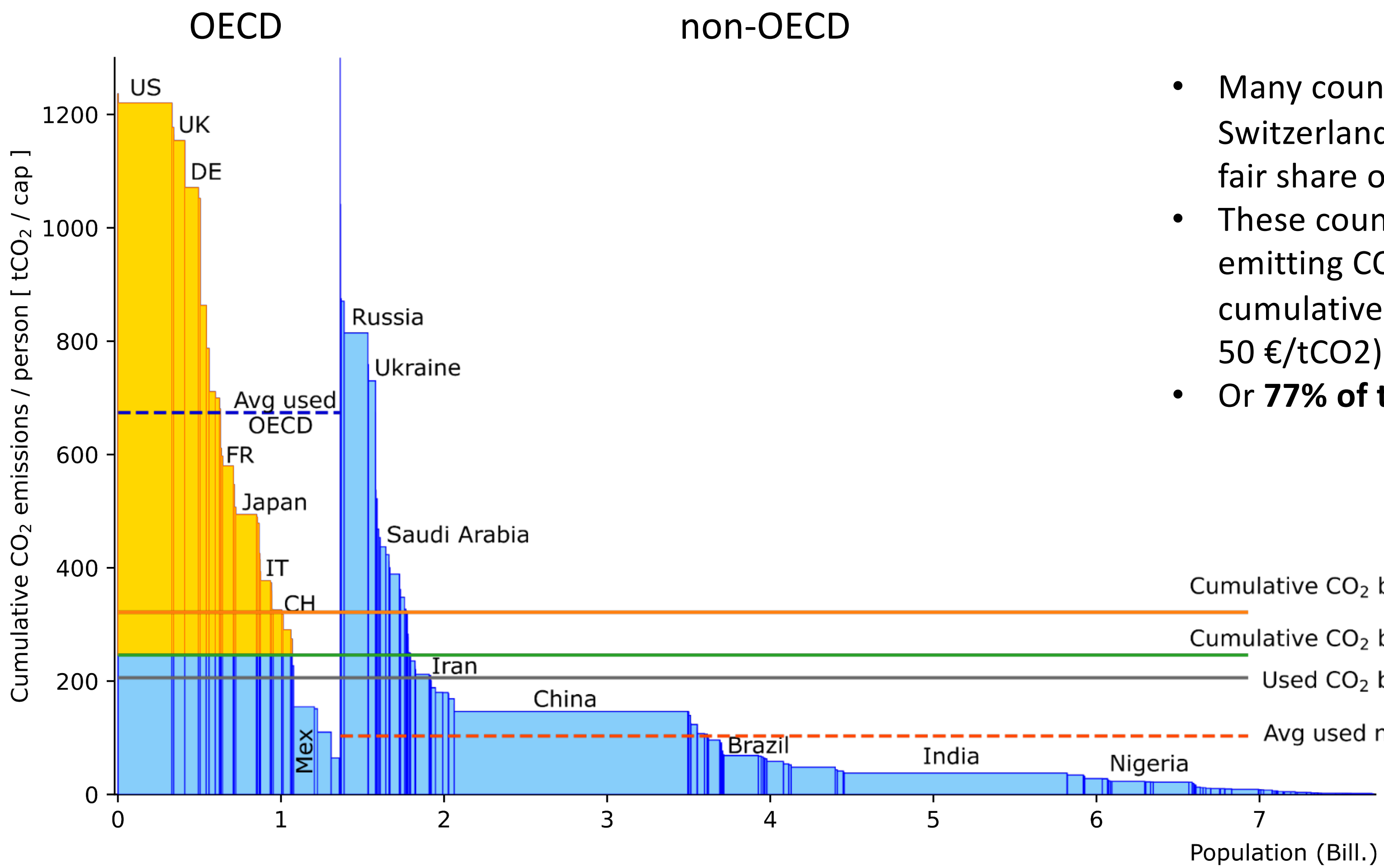
The case of Switzerland

$$CO_2 = \text{Population} \cdot \frac{\text{GDP}}{\text{cap}} \cdot \frac{\text{Energy}}{\text{GDP}} \cdot \frac{CO_2}{\text{Energy}}$$



Sources: BAFU, BFE, BFS, The Maddison Project

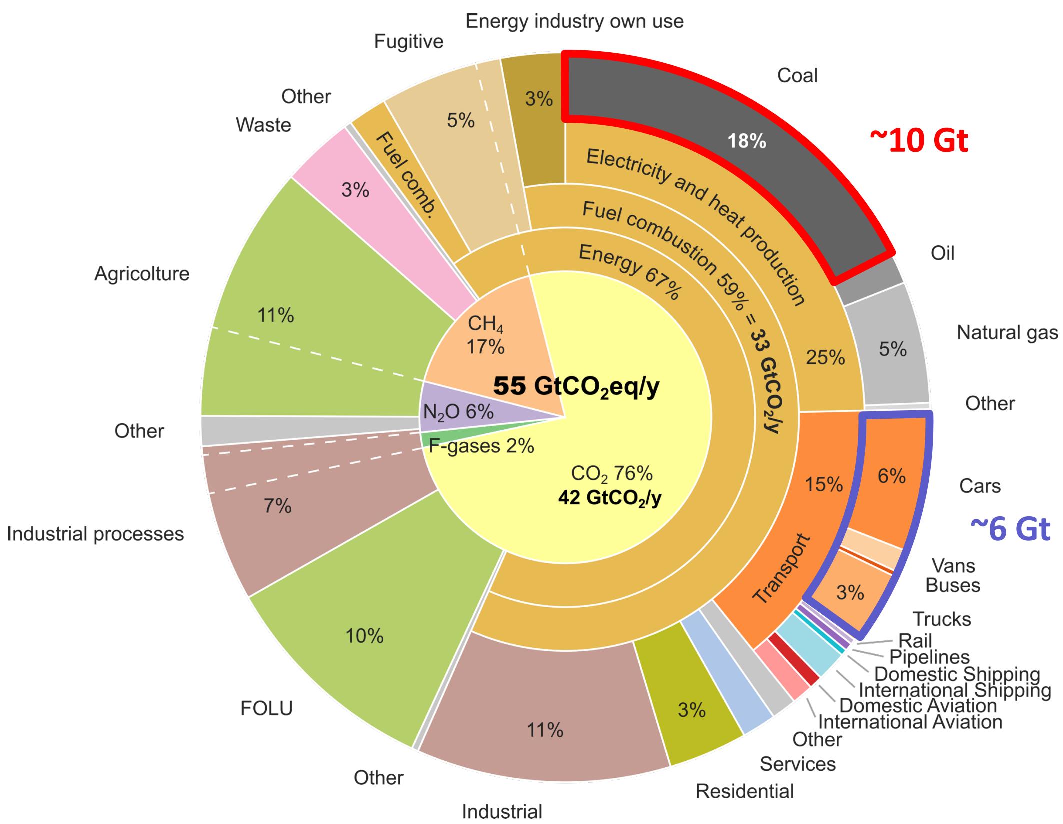
Historical cumulative emissions condemn early industrialized countries



- 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

The big question from a systemic viewpoint: Electrify end-use sectors or decarbonize electricity generation first?

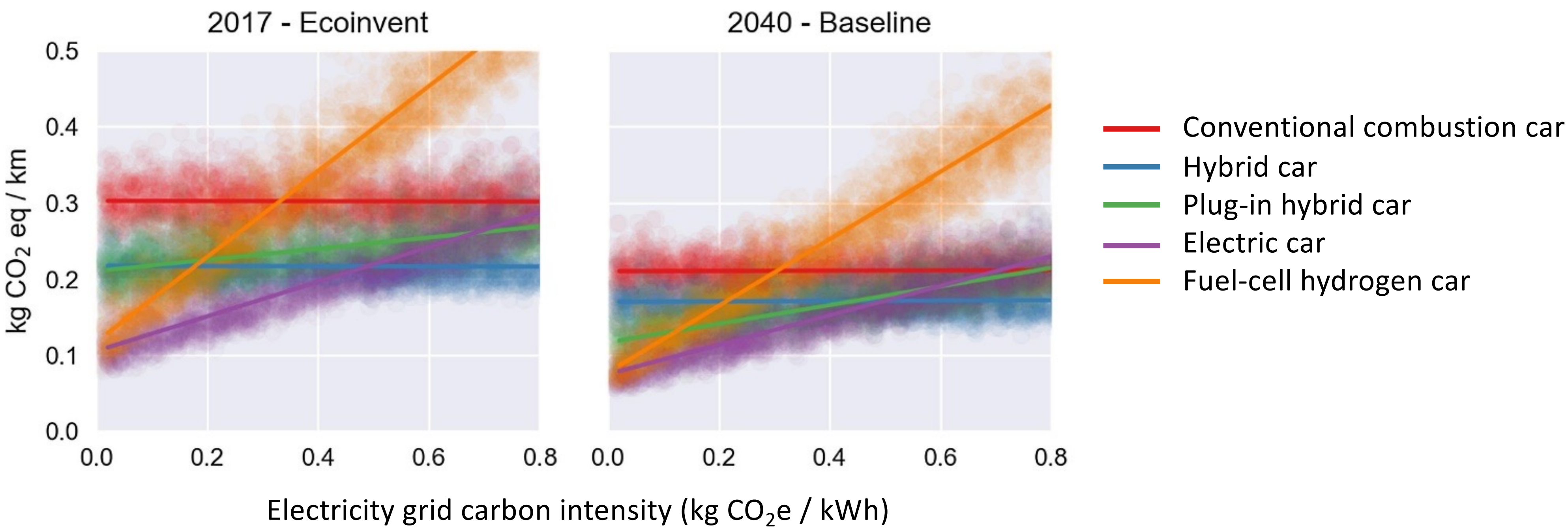


Switching from Coal to Gas (feasible today for **~50 €/tCO_2**) saves **6 GtCO2**

Roughly equivalent to **all emissions from road transport**, which however requires **300-600 €/tCO_2** to be electrified!

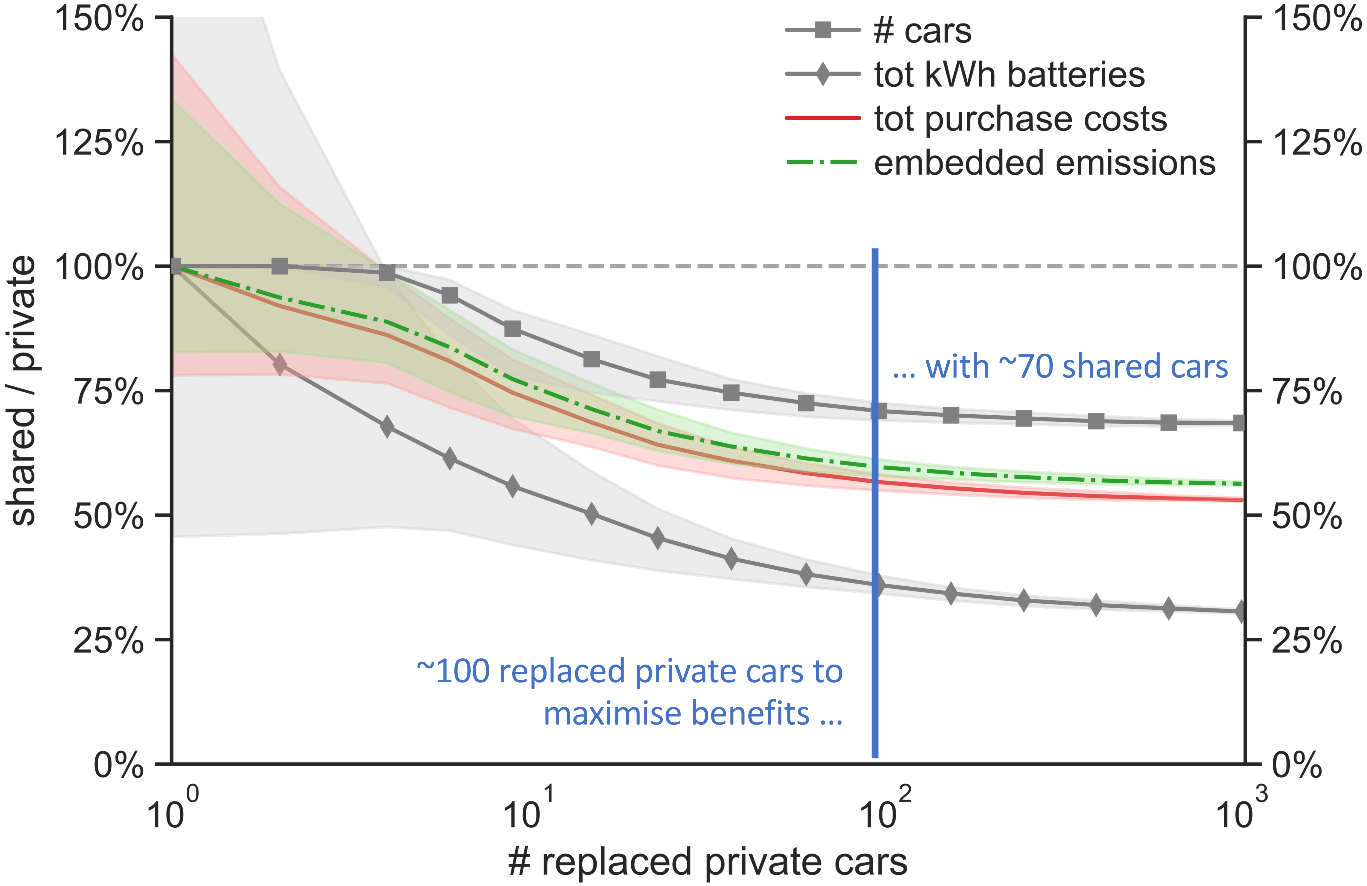
Source: elaborations based on Cox et al. (2020)

Climate effect of different car propulsion technologies



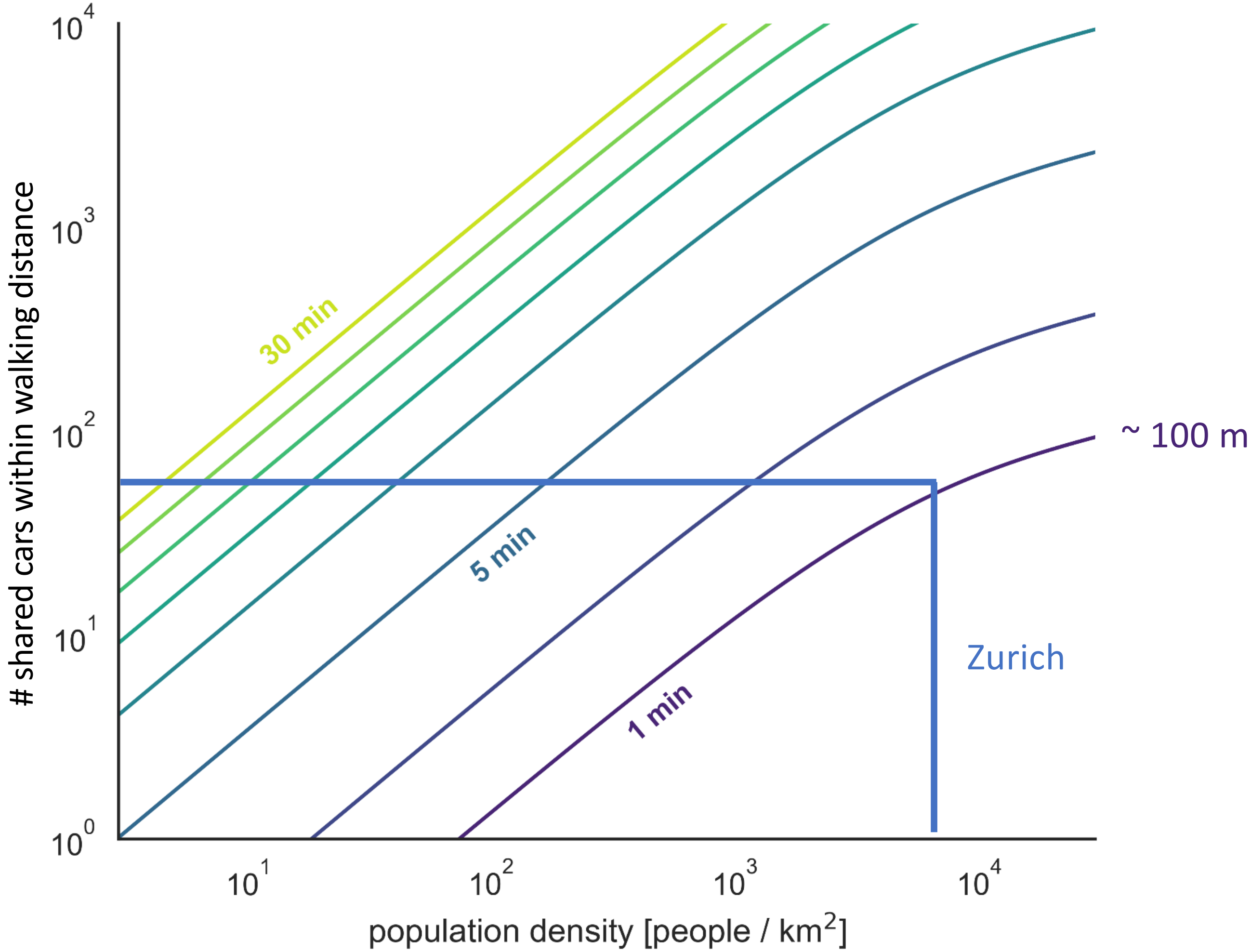
Benefits of sharing the ownership of electric vehicles

Assuming 5 out of 250 driving days a year are unserved in both private and shared ownership models



G. Pareschi et al. (2021), Seizing the low-hanging benefits of shared electric vehicles, In preparation for submission

Walking time to find a car to share



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