ETH zürich

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

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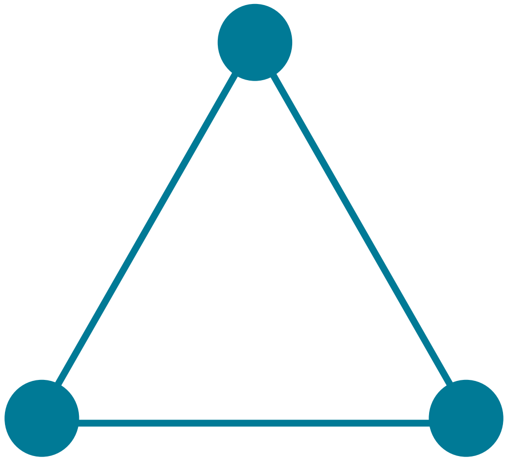
With contributions by G. Pareschi (ETH Zürich)

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)



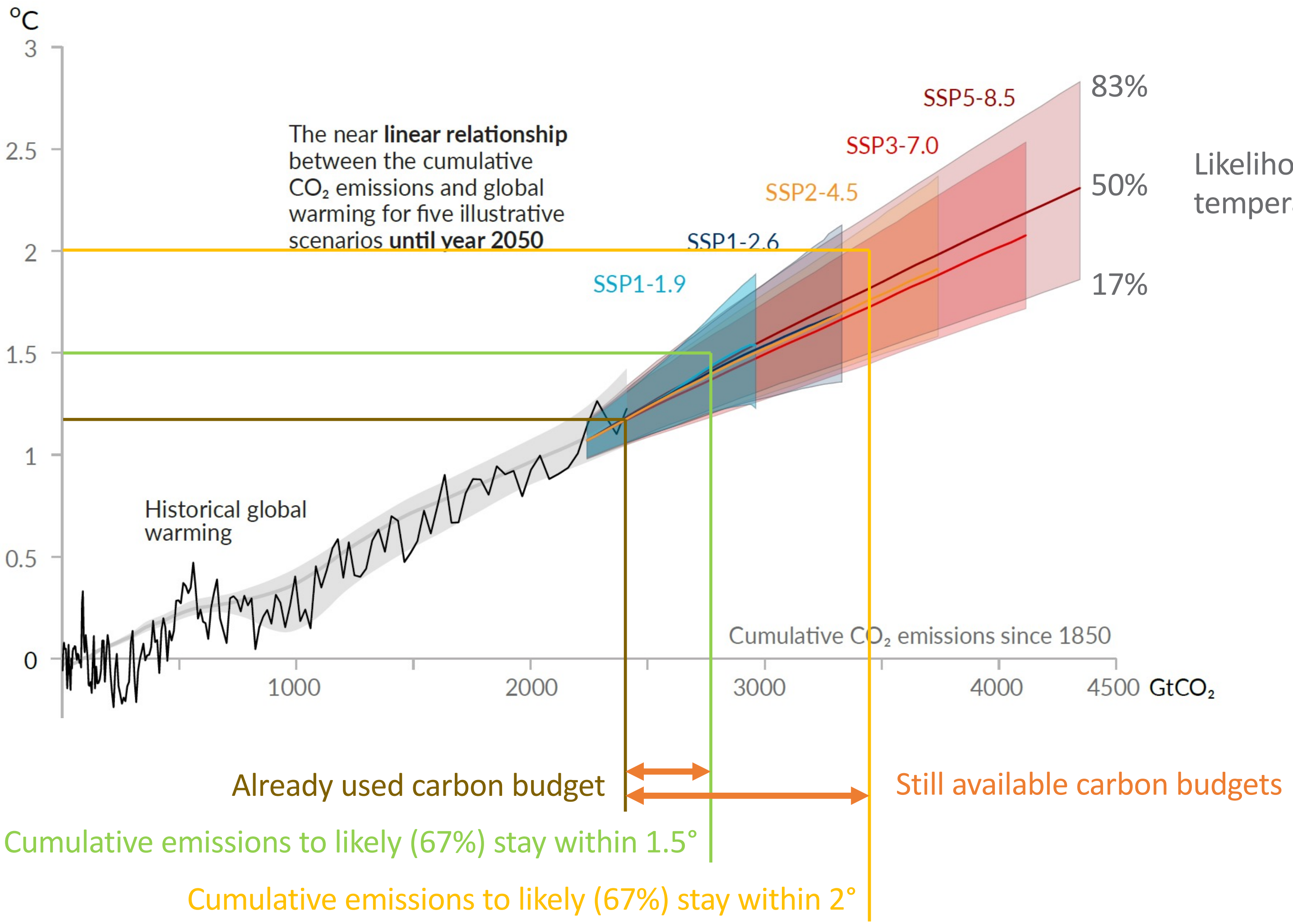
→ Partially conflicting goals
→ Optimization required

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**

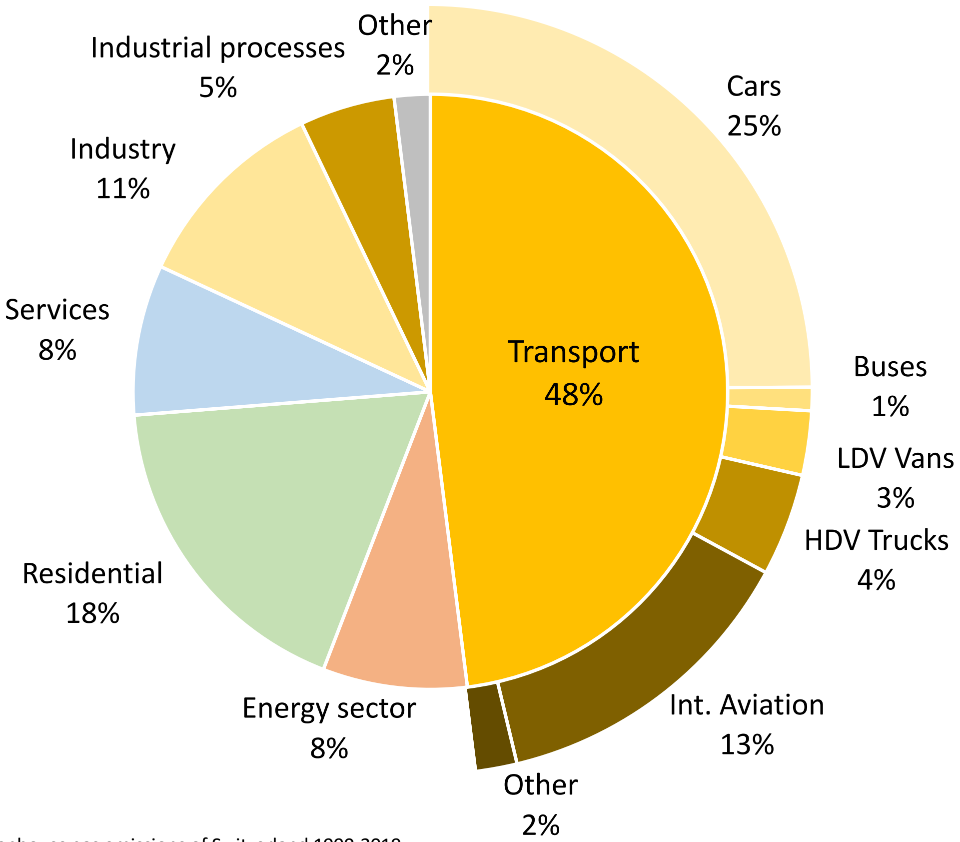
Every tonne of CO_2 adds to global warming



Sources: IPCC AR6 WG1

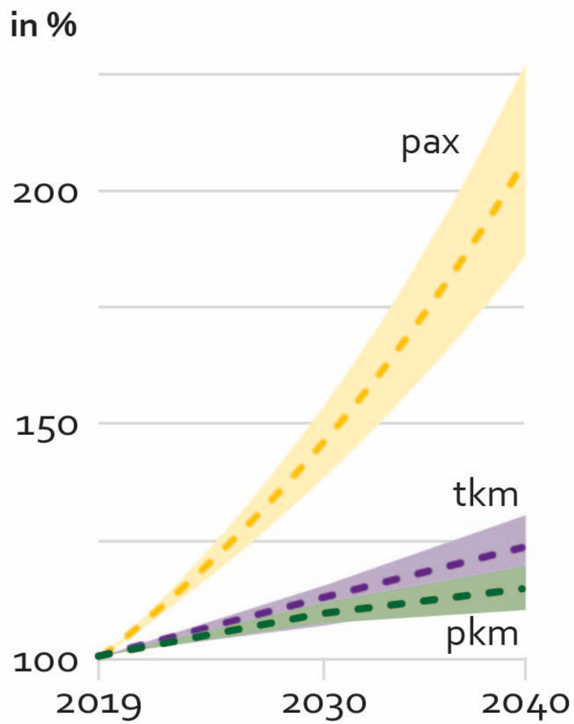
Relevance of Transportation for the Swiss CO_2 Emissions

Total 2019: 43 $MtCO_2$/y



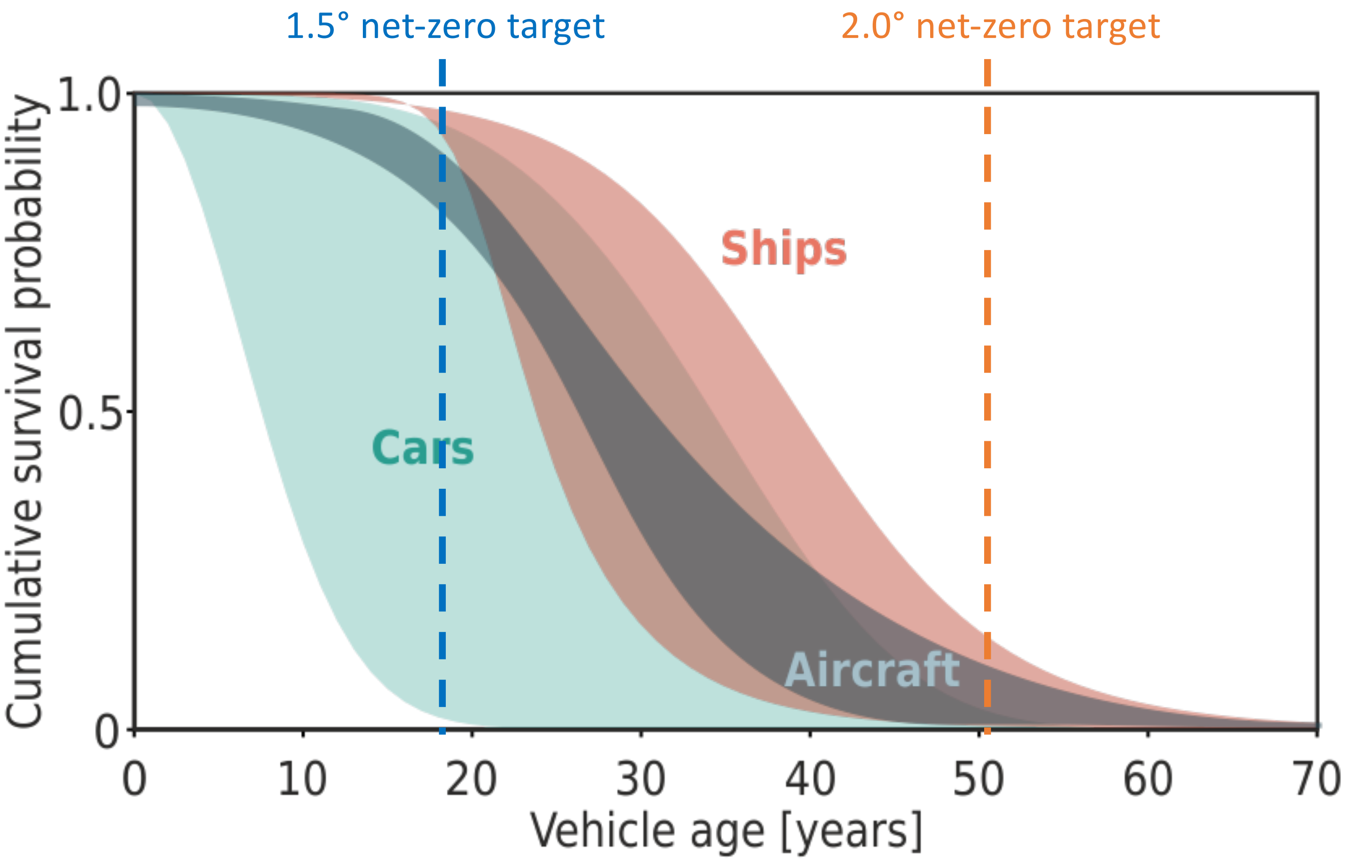
Sources: BAFU, Greenhouse gas emissions of Switzerland 1990-2019

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*:*

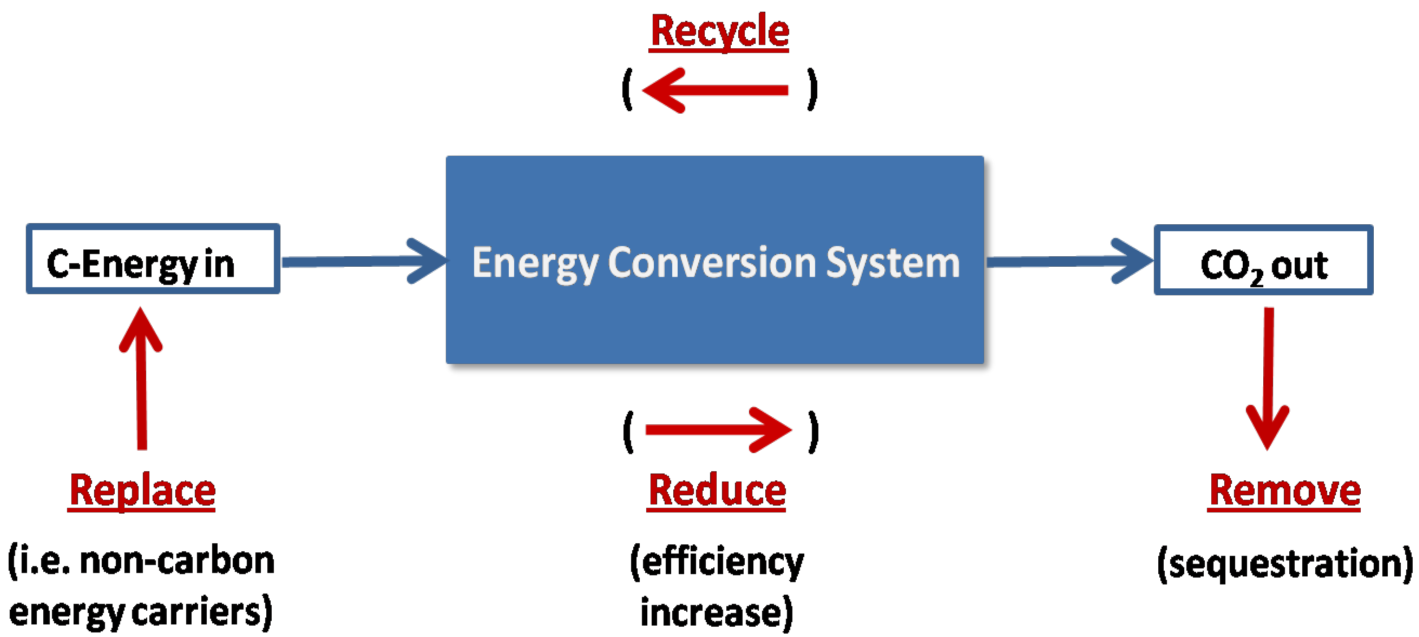
- Power plants → 20-50 years
- Buildings → 30-100 years
- Industrial processes → > 20 years
- Roads, Grids, Refineries → 50-100 years

- 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?

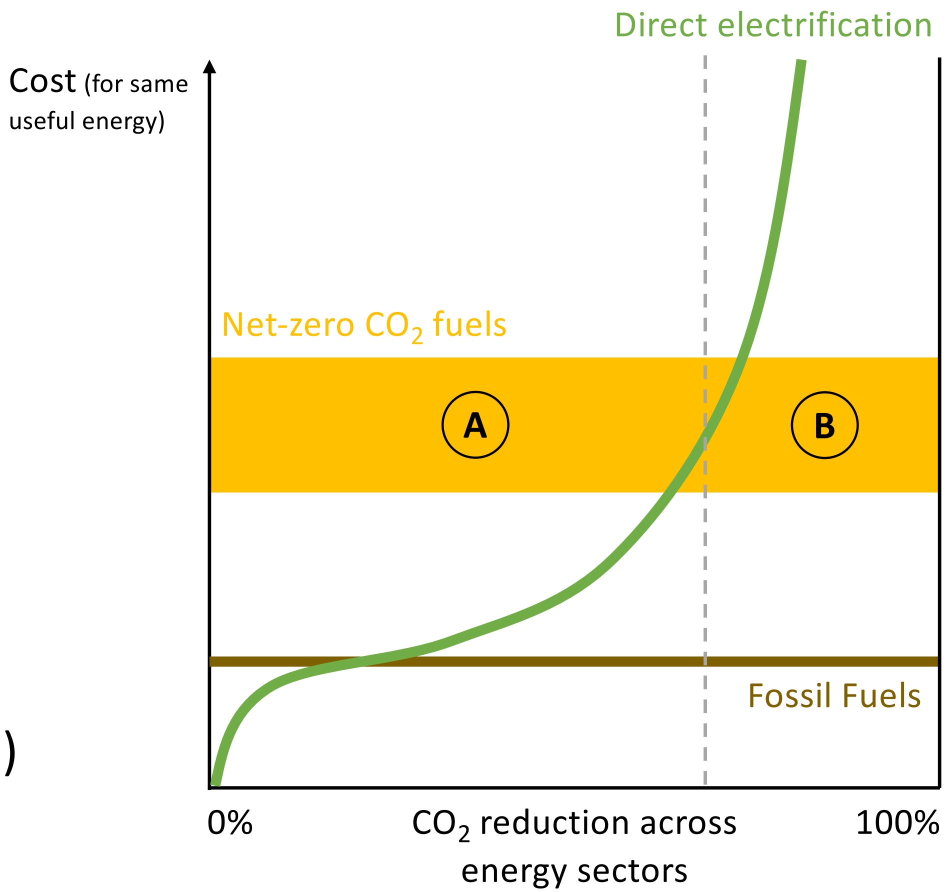
→ (the four **R**'s – strategy)



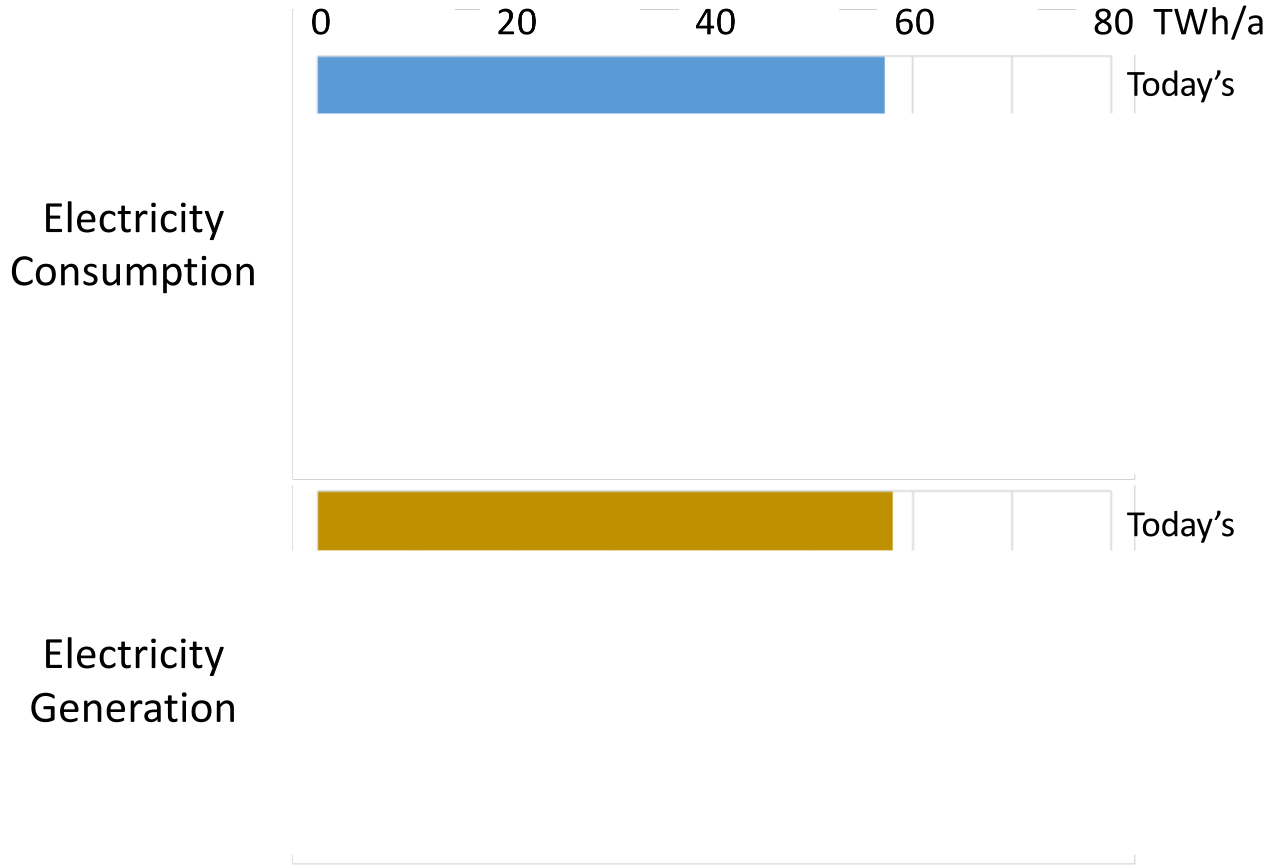
Two complementary “Replace” strategies

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?

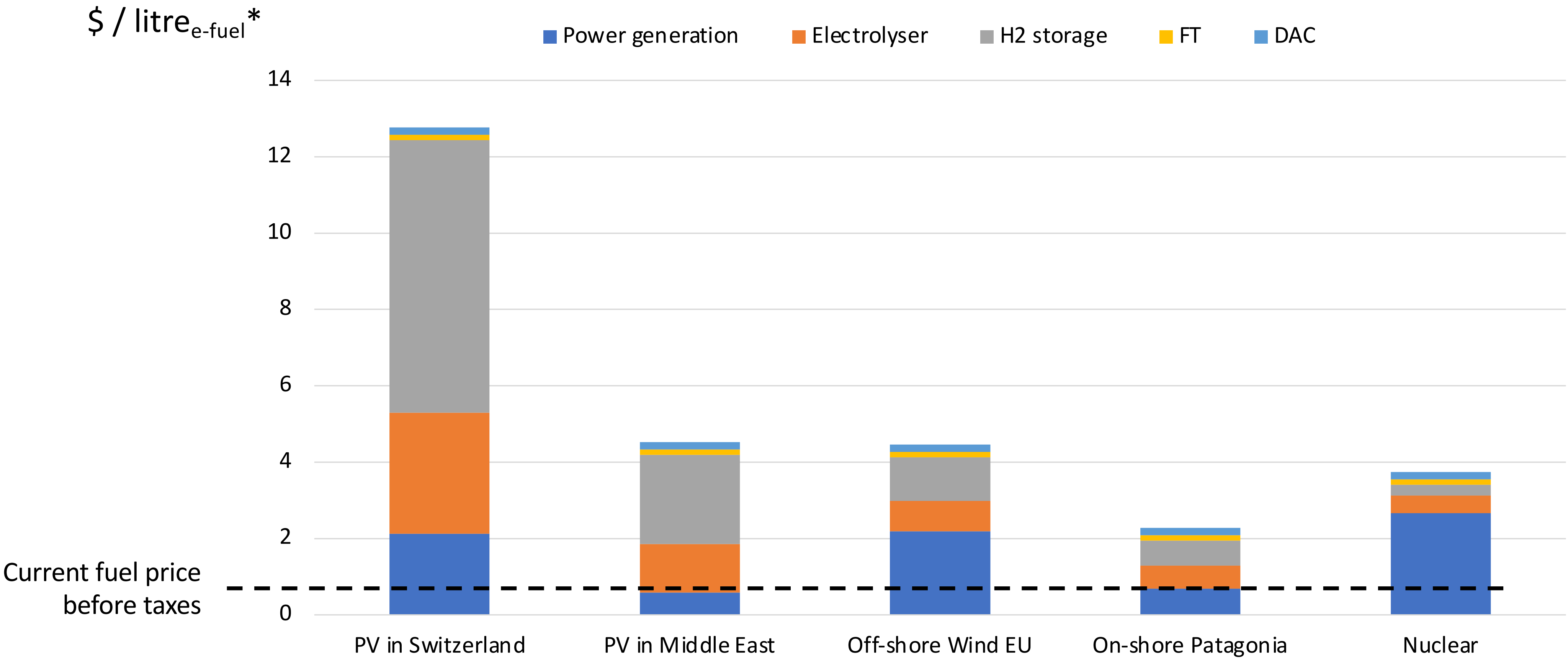
	Full-load hours	Peak capacity	CAPEX $ / kW$_{peak}$	Lifetime years	LCOE $ / kWh	Annualized costs power generation bill. $	Annualized costs electricity to e-fuel* bill. $	Total annualized costs bill. $
PV in Switzerland	1’000	**70 GW**	1’100	25	0.09	6.0	29.8	**35.8**
PV in Middle East	2’500	**28 GW**	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)

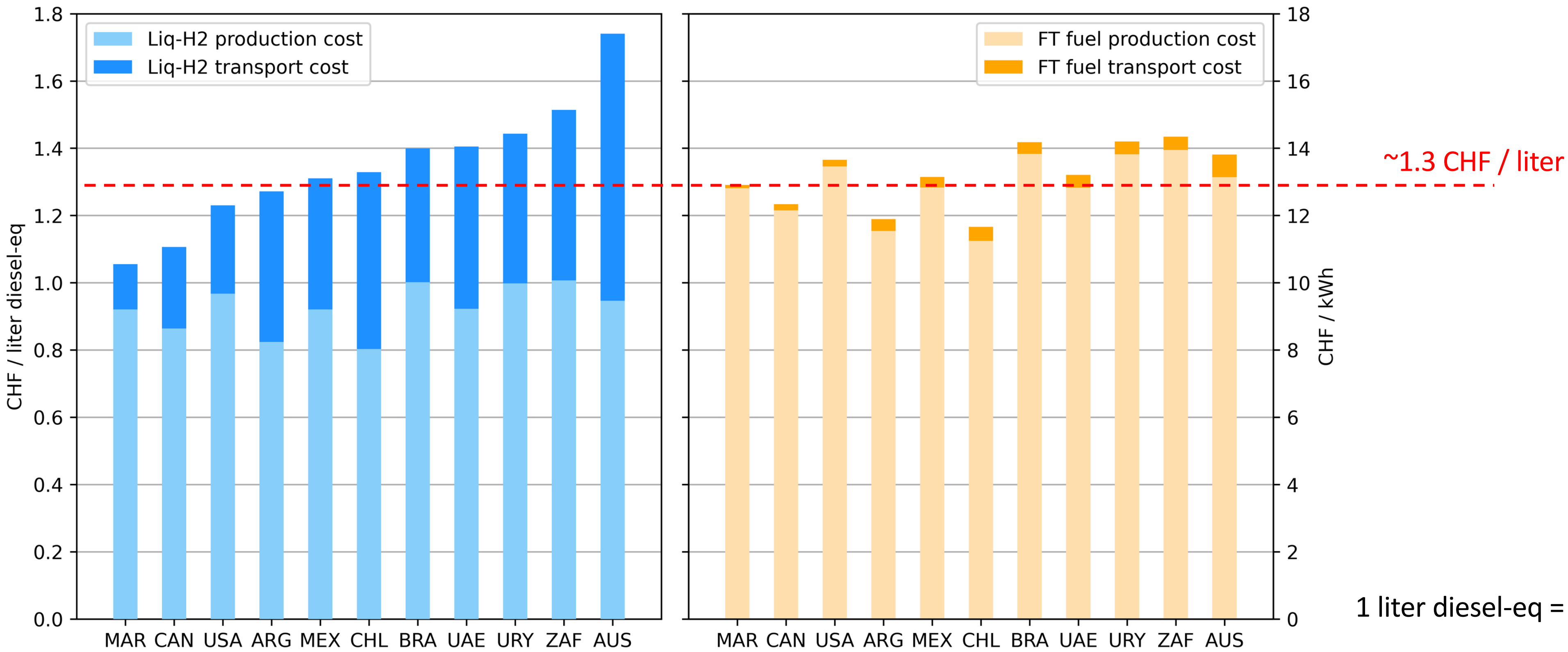
Current costs of generating e-fuels via different paths



*Excluding costs for transport

Preliminary results G. Pareschi (LAV ETHZ)

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



1 liter diesel-eq = 10 kWh

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.

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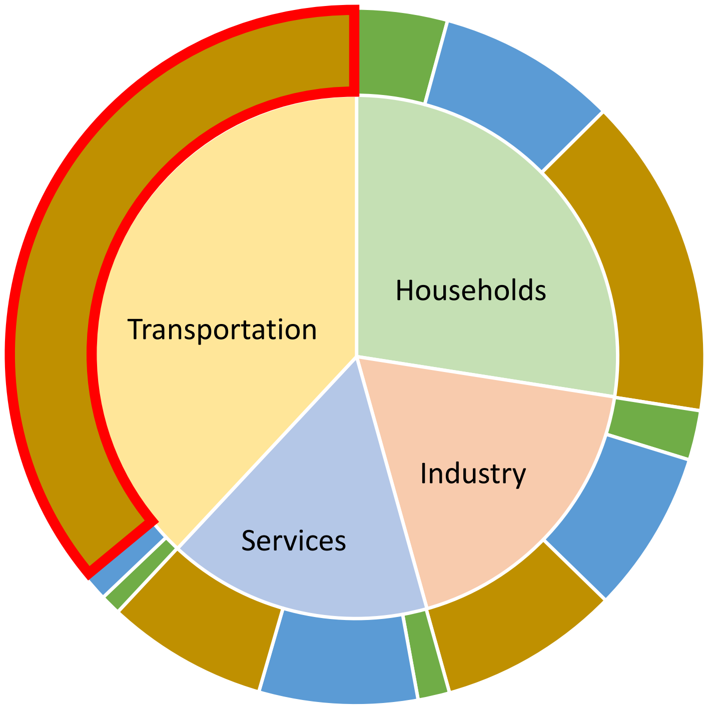
Relevance of Transportation for Final Energy Demand and CO_2 Emissions

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

Or 48% of all domestic CO_2 emissions!!

Total: 229 TWh / y



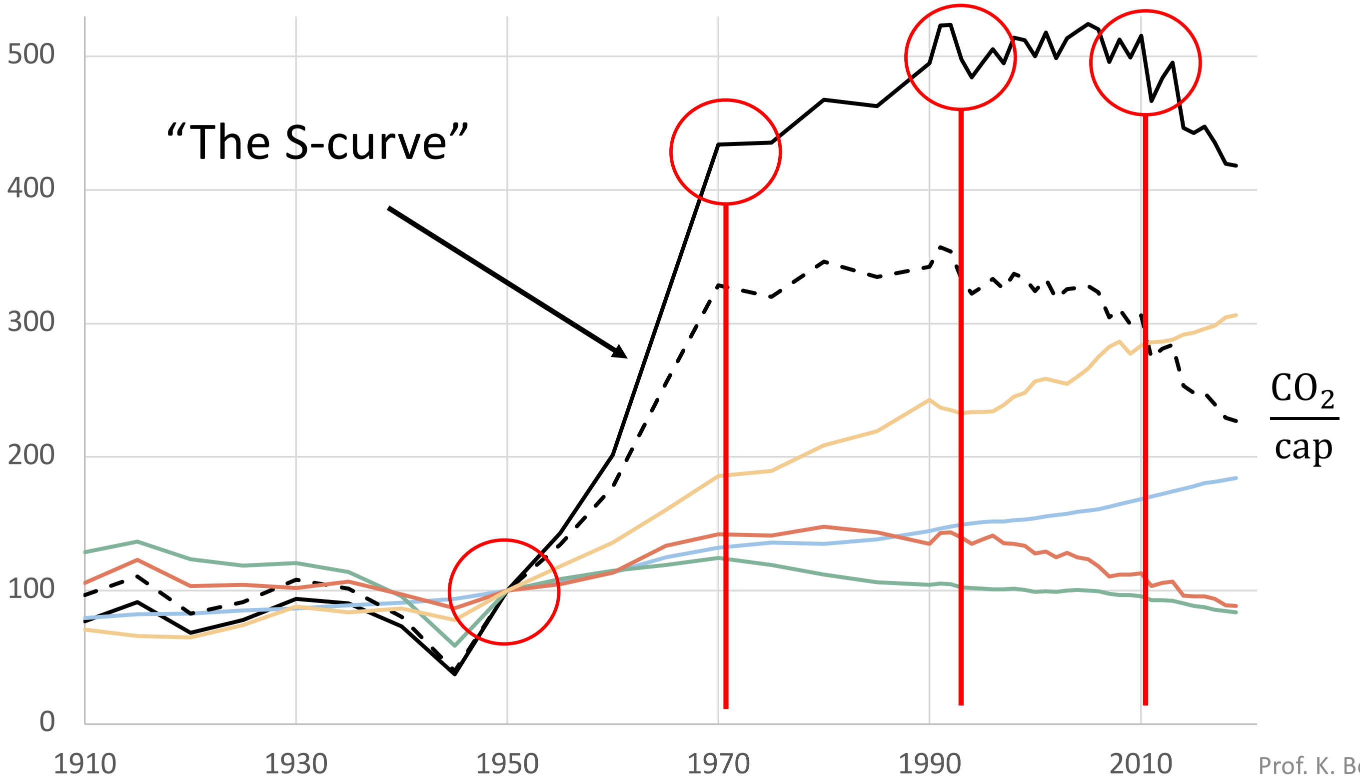
Fossil fuels	153 TWh
Electricity	56 TWh
Others non-fossil	21 TWh

Sources: BFE, Schweizerische Gesamtenergiestatistik 2019

Drivers behind CO_2 growth… and CO_2 reduction

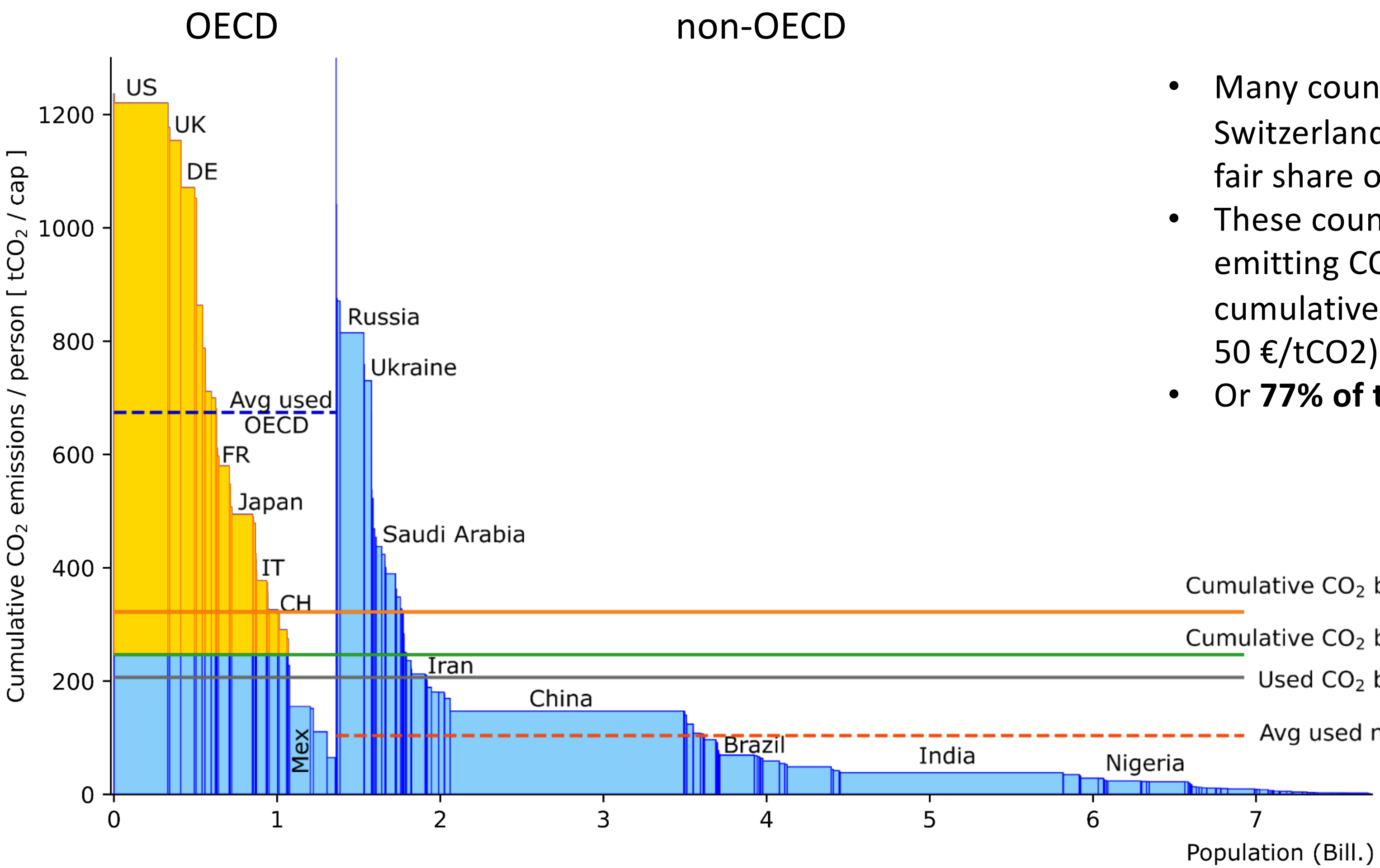
The case of Switzerland

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



Sources: BAFU, BFE, BFS, The Maddison Project

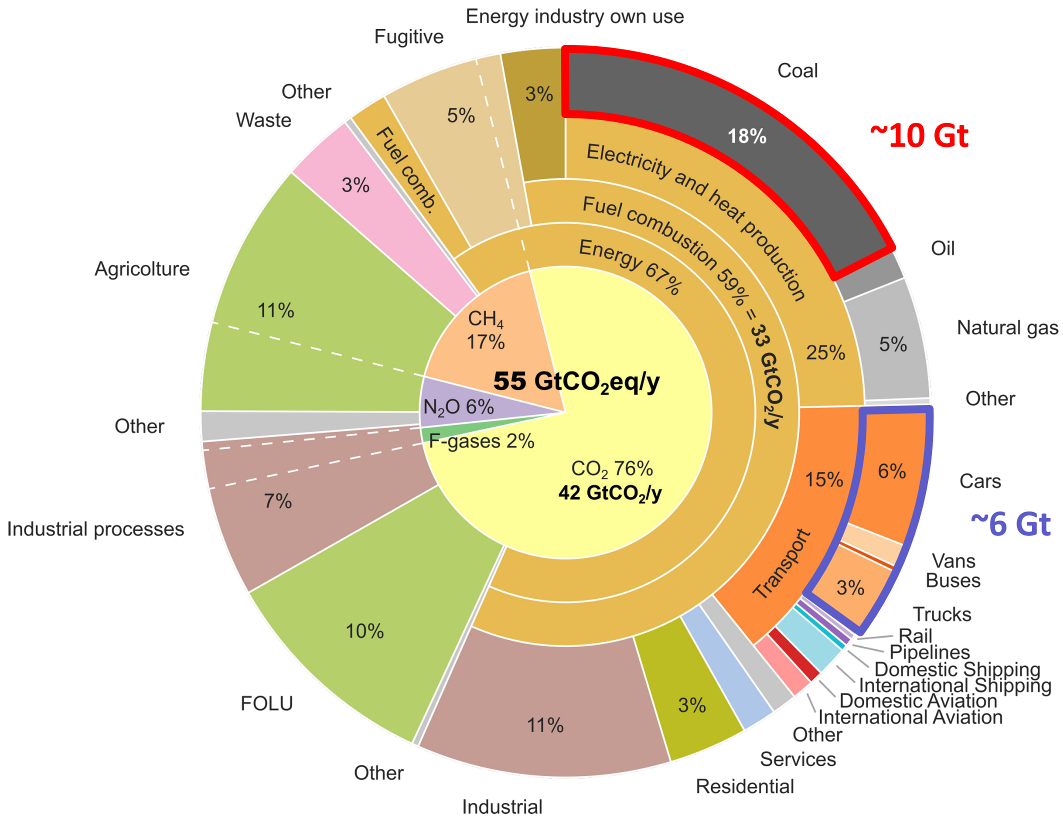
Historical cumulative emissions condemn early industrialized countries



- 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?

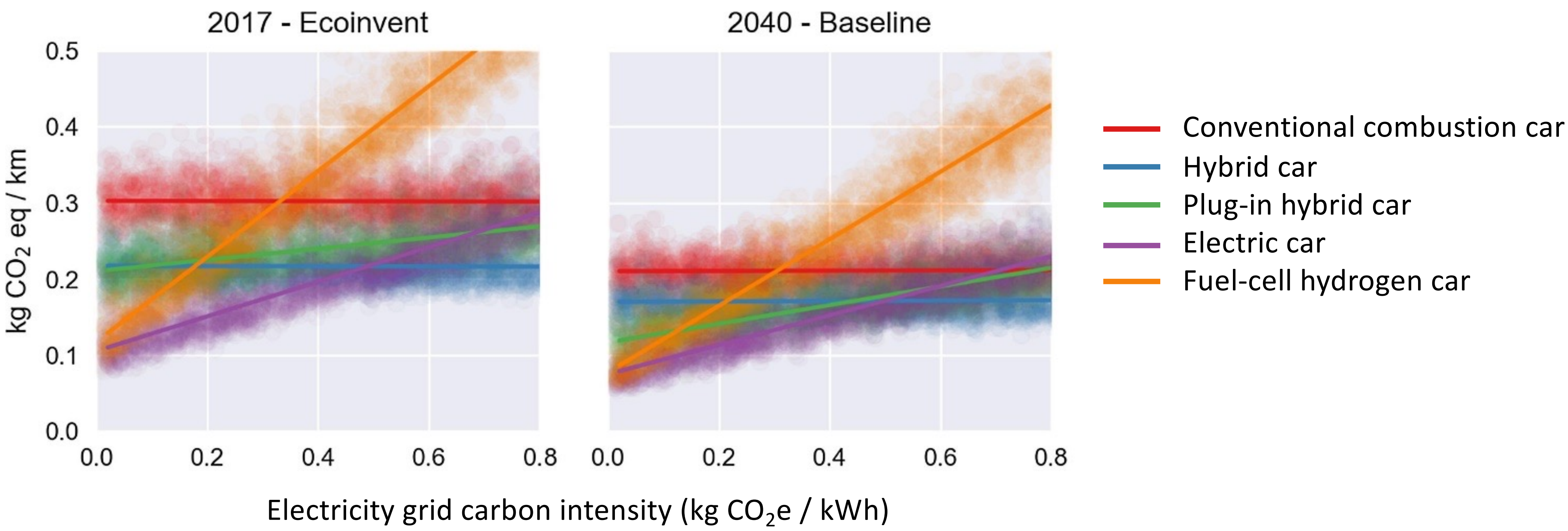


Switching from Coal to Gas (feasible today for **~50 €/tCO_2**) saves **6 GtCO2**

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

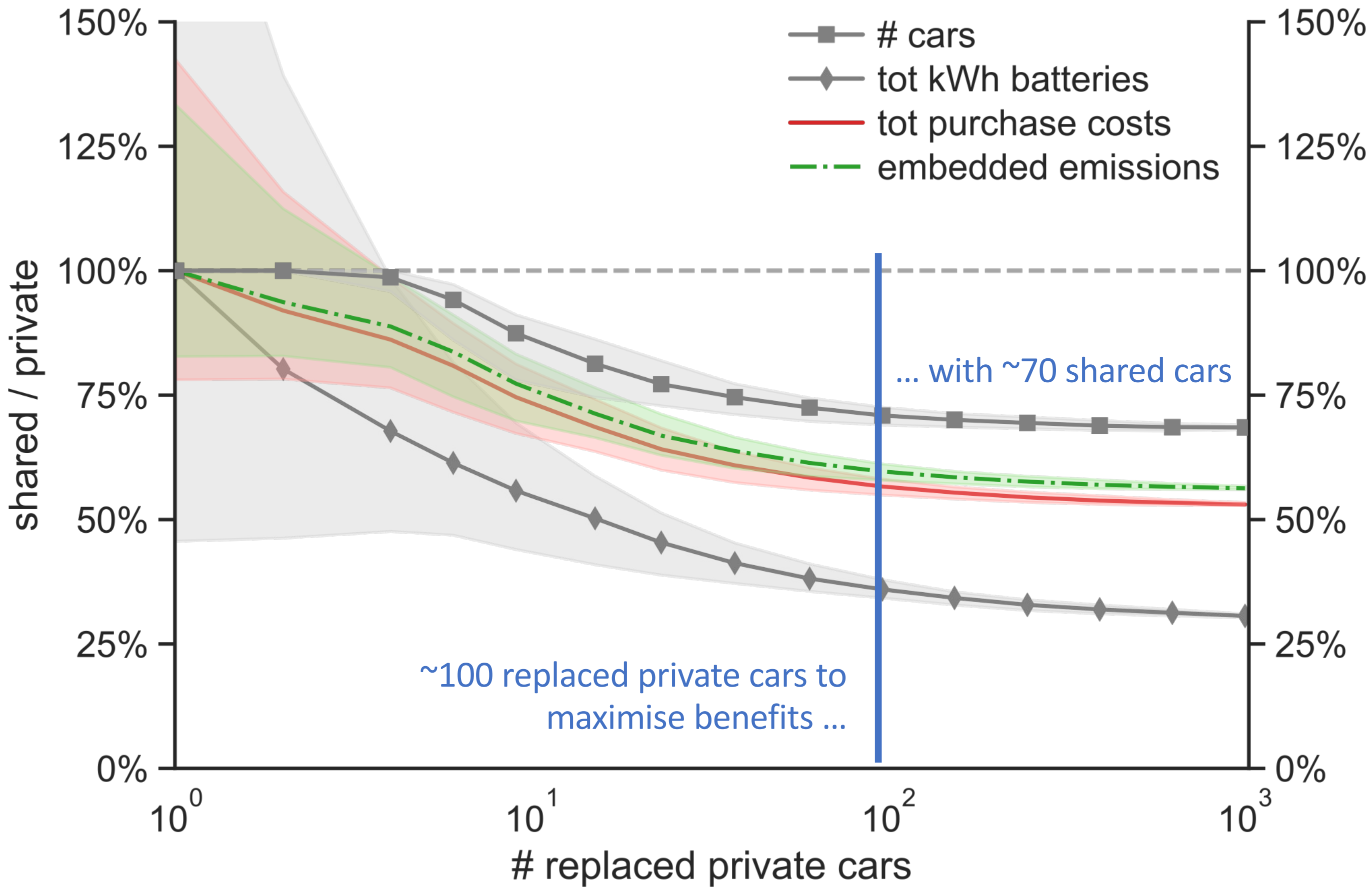
Source: elaborations based on Cox et al. (2020)

Climate effect of different car propulsion technologies



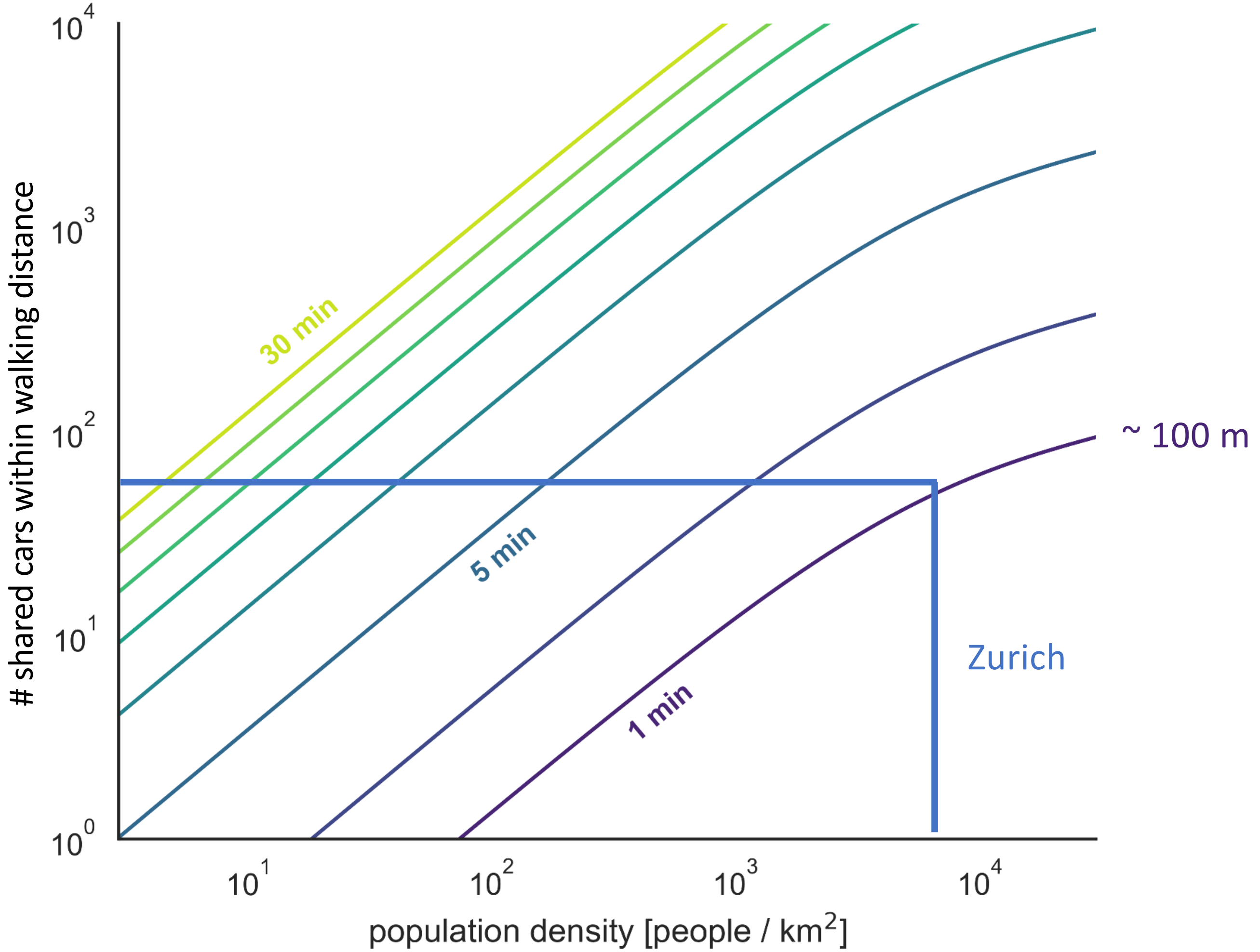
Benefits of sharing the ownership of electric vehicles

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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