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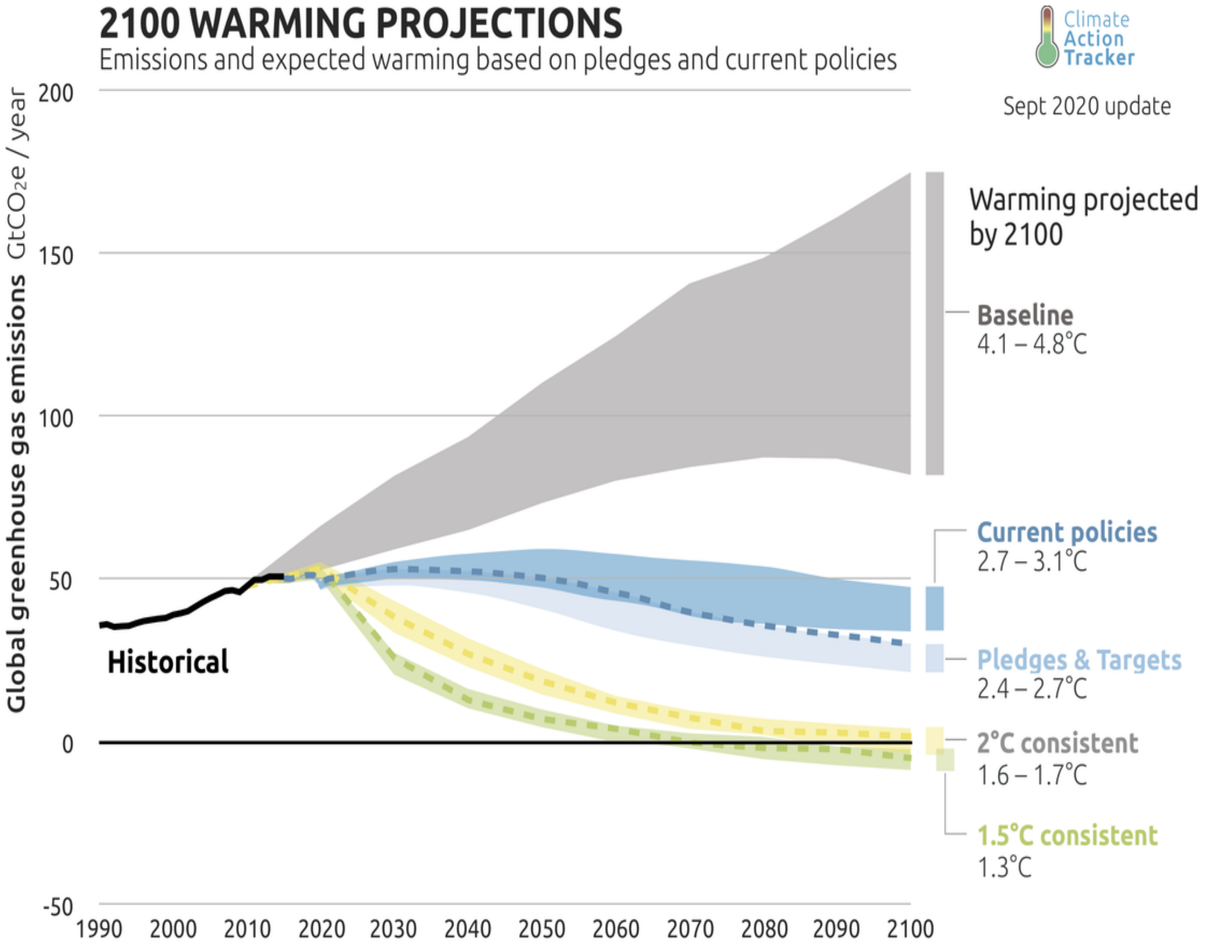
Energy System transformation pathways
Towards Net-Zero emissions in 2050

Dr. Evangelos Panos – Paul Scherrer Institute (PSI)

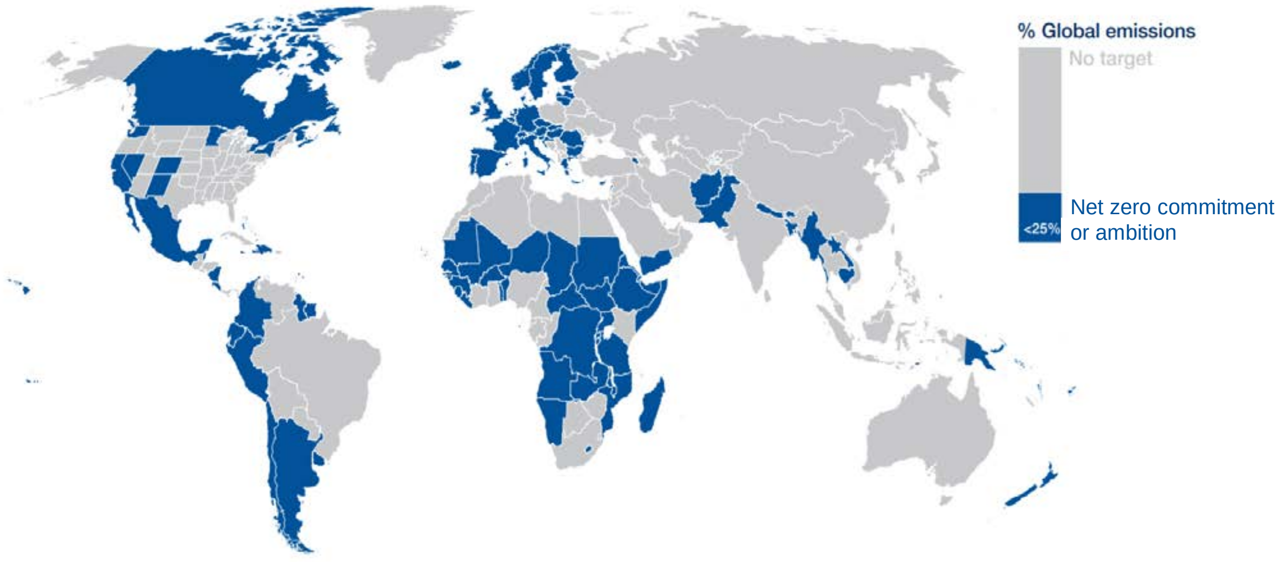
SCCER SoE Annual Conference, ETHZ, 02.11.2020

The world needs to move to net-zero…



… but only few countries have a net-zero ambition to date (1/2020)

121 countries are now aiming to be carbon neutral, but these account for less than 25% of emissions

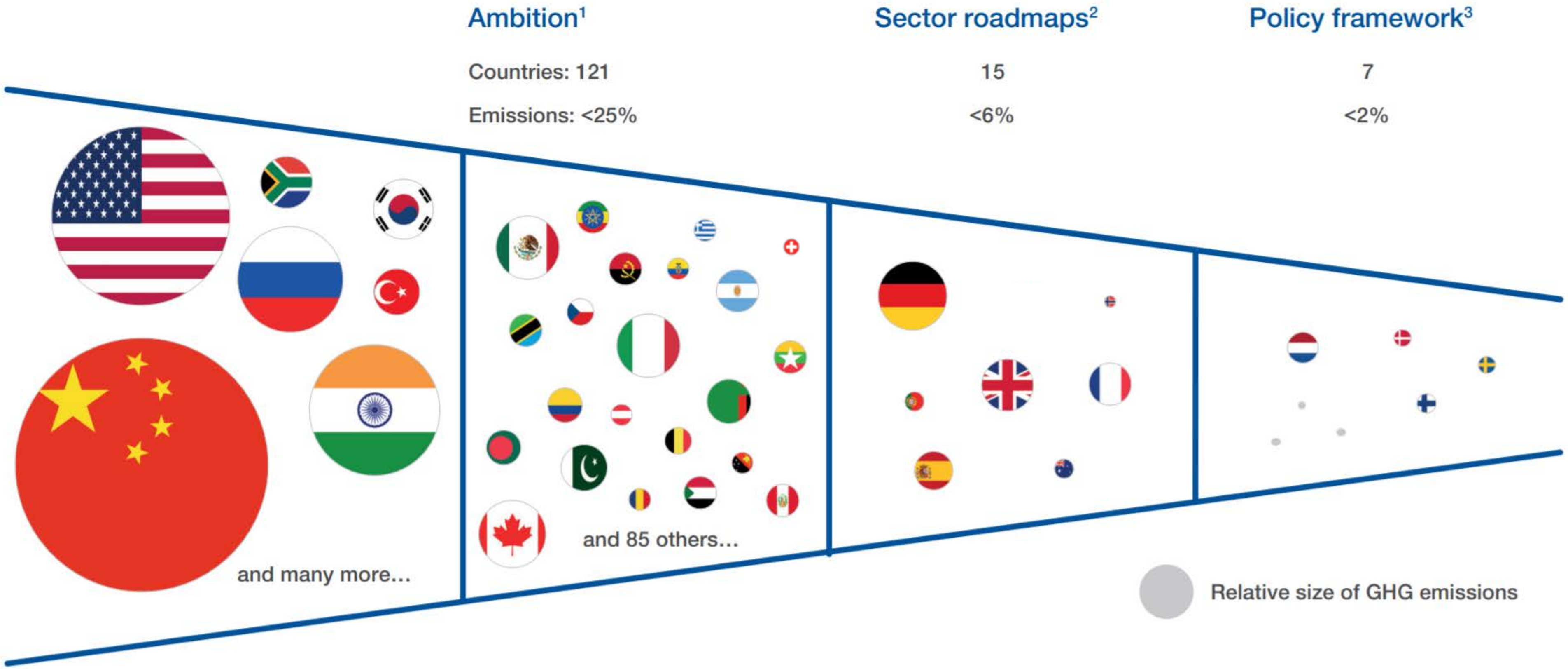


Note: 8 US States - California, New York, Hawaii, Washington, New Mexico, Nevada, Colorado, Minnesota (Washington, New Mexico, Colorado, Minnesota & Nevada committed to 0 carbon energy). China has announced in September 2020 a net-zero ambition in 2060

Sources: COP25; CAIT data from World Resources Institute and Eurostat; BCG analysis

Source: Based on Boston Consulting Group Analysis, 2020.

… and even fewer countries have sufficient policies in place (1/2020)



1. Countries with a net-zero ambition; 2. Ambition translated into sector roadmaps with targets; 3. Targets supported by an effective policy framework.
Note: Countries with emissions >40 million tonnes and those with emissions >75 million tonnes with a net-zero ambition are represented graphically by a flag.

Sources: Emissions data from CAIT (from the World Resources Institute) and Eurostat; Policy analysis by BCG, referencing the IMF, Climate Action tracker and government websites; BCG analysis China has announced in September 2020 a net-zero ambition in 2060

Source: Based on Boston Consulting Group Analysis, 2020

To achieve net-zero at a global scale would require strong efficiency policies and electrification in the demand sectors…

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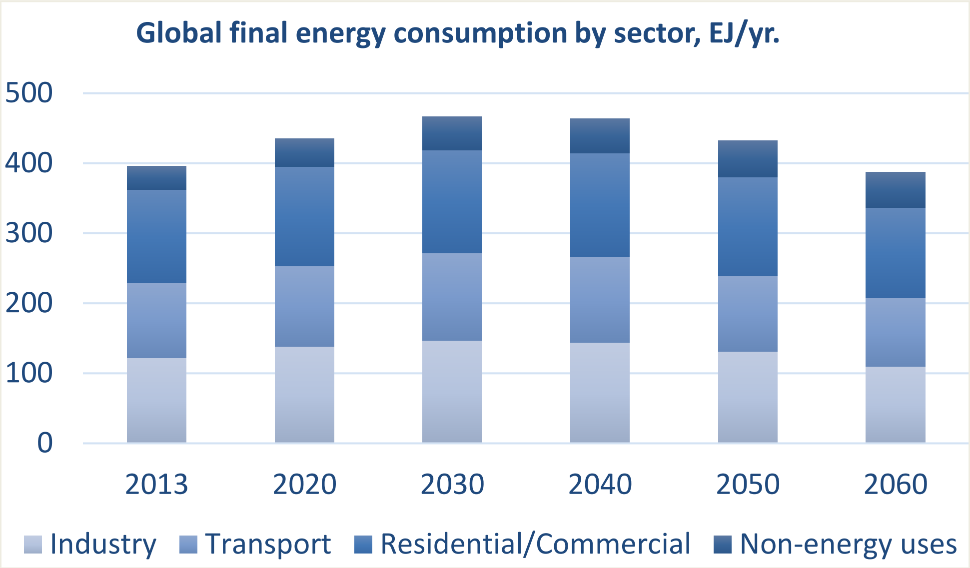
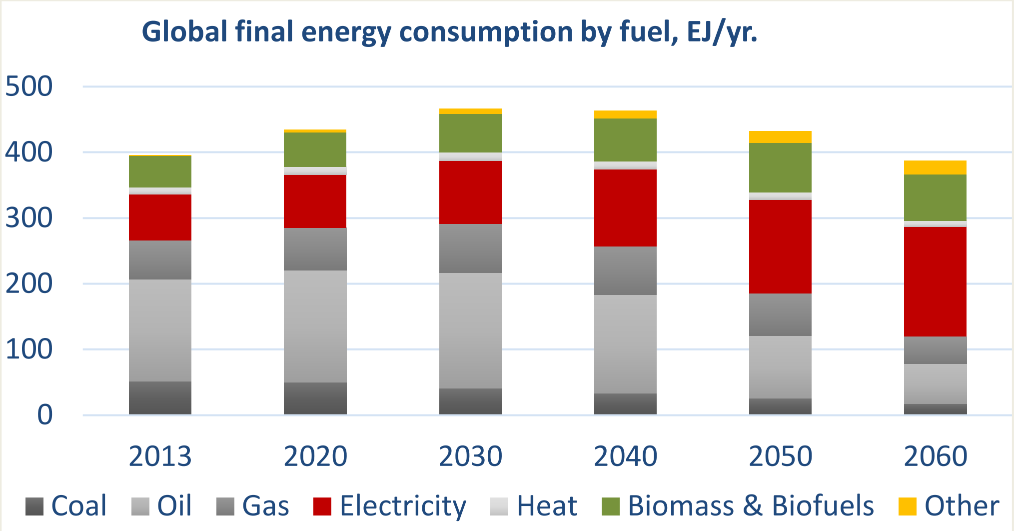


- Accelerated decoupling of economic growth from energy consumption
- Transport & Industry to achieve the highest demand reductions
- Increased renovation in existing buildings following by stringent energy consumption and emission standards for new constructions
- Global coordination to avoid laggards in the new energy consumption paradigms

- Continuous electrification of space heat
- Electrification of passenger transport, freight switches to hydrogen/bioenergy
- Industry shifts away from coal towards electricity, gas and bioenergy
- Hydrogen and e-fuels emerge after 2030, mainly in mobility and industry

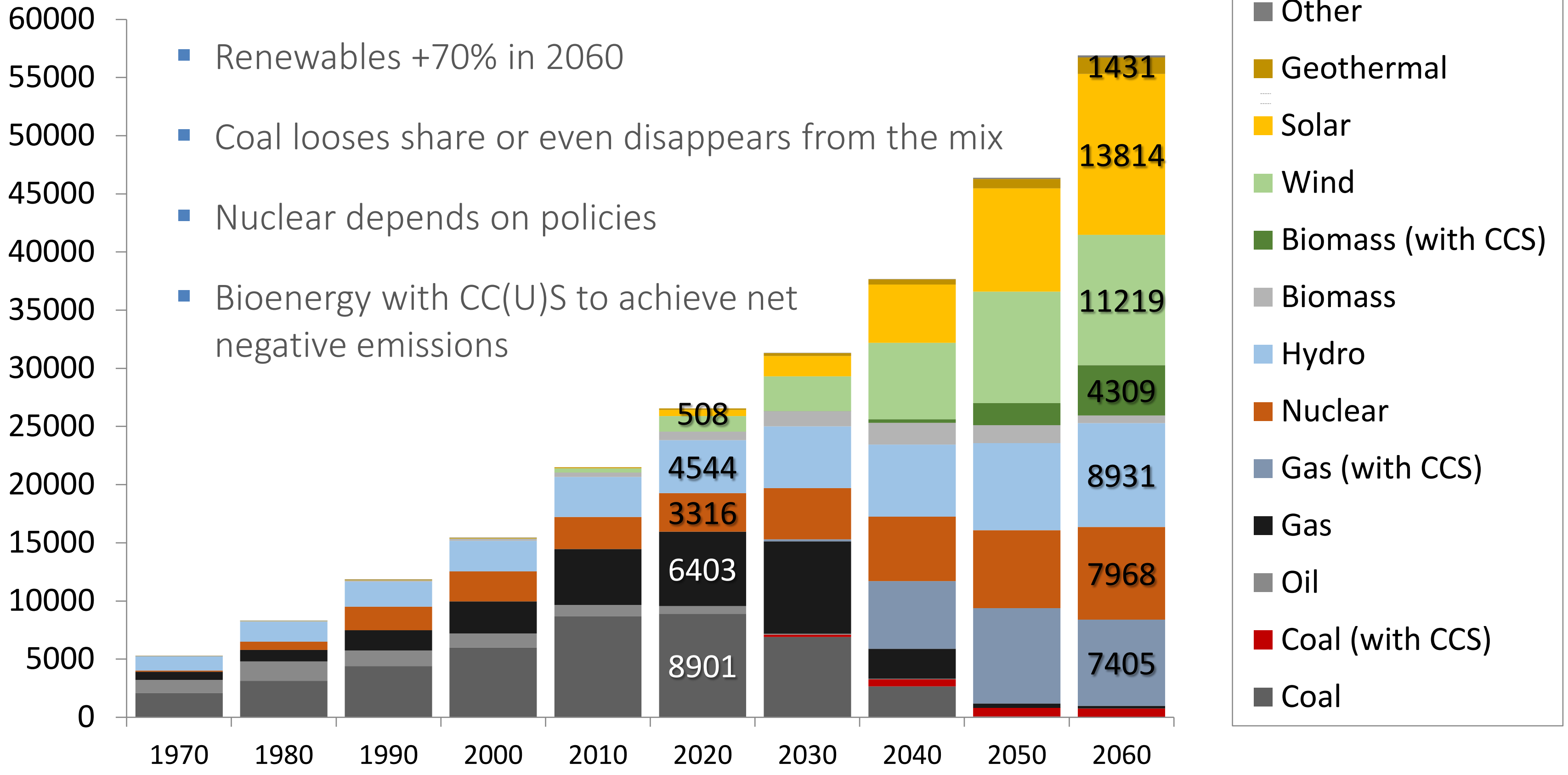


PSI quantified global energy sector developments with the GMM model for World Energy Council and ETSAP
Sources: World Energy Council, PSI and Accenture (2019), Kober et al. (2020) Kober et al. (2018)
Results from Symphony 1.5 Scenario

… which means that the electricity production needs to be doubled compared to today, decarbonised and even deliver negative emissions

Global electricity production, TWh/yr

- Renewables +70% in 2060
- Coal looses share or even disappears from the mix
- Nuclear depends on policies
- Bioenergy with CC(U)S to achieve net negative emissions



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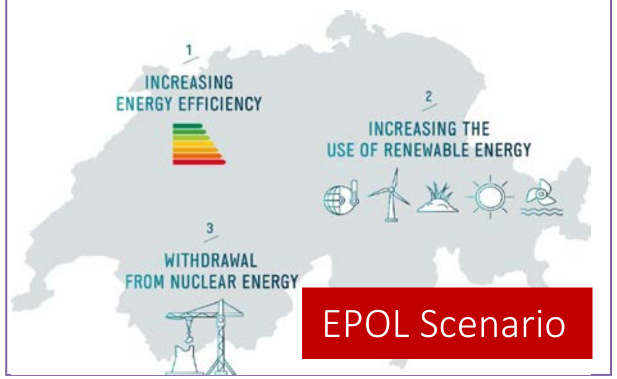
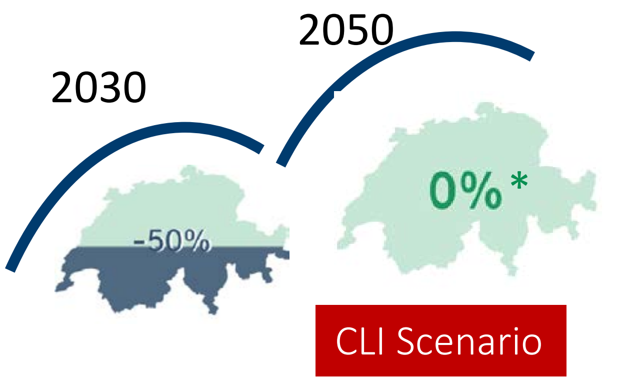
Results from Symphony 1.5 Scenario

Switzerland boosts green goals aiming at carbon neutrality by 2050

Energy policy objectives

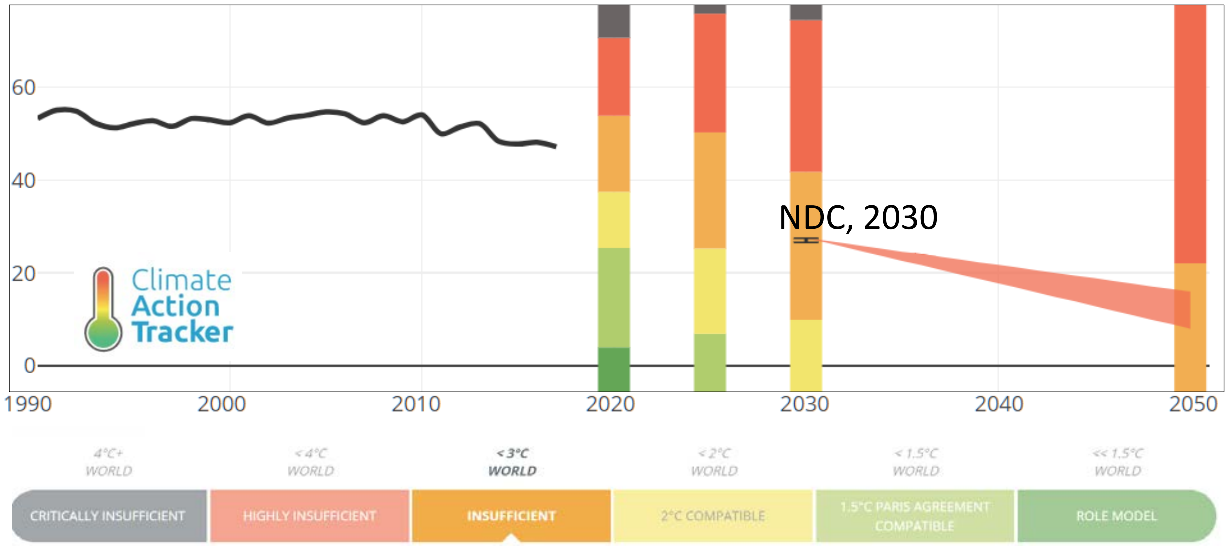


Climate policy objectives

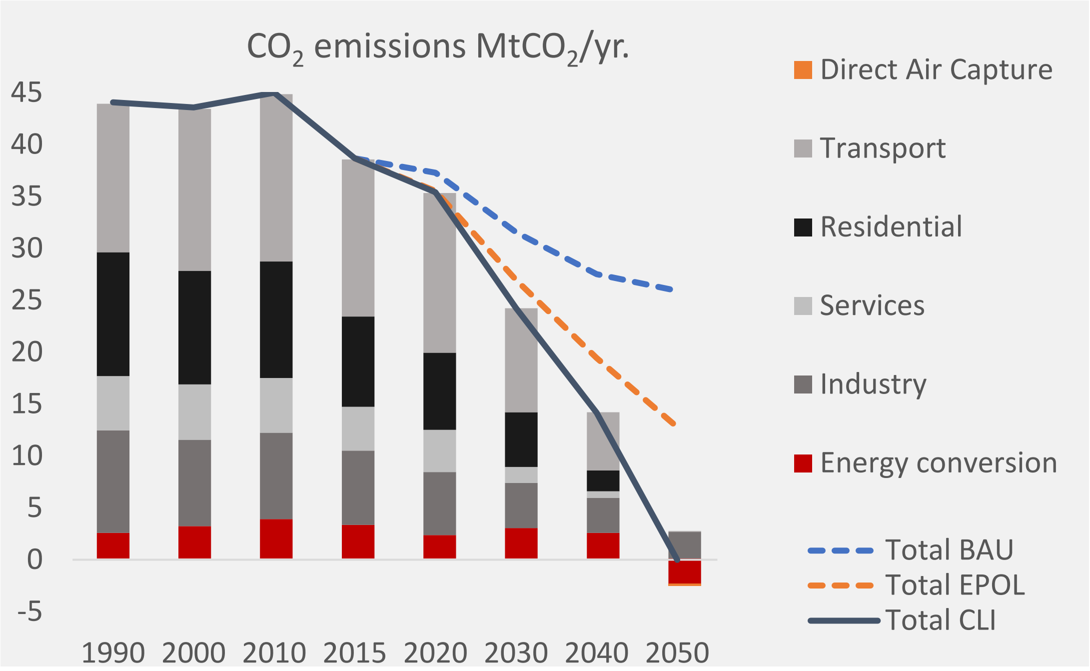


* Federal Council announcement, 2019

Swiss GHG emissions trajectory under current -85% pledges, Mt CO_2eq/yr



Emissions trajectory in the CLI scenario to achieve net-zero (energy system & industrial processes only)



PSI quantified Swiss energy sector developments with the Swiss TIMES energy systems model for SCCER Joint Activity Scenarios and Modelling (SCCER JASM)

Source: Panos et al. (2020)

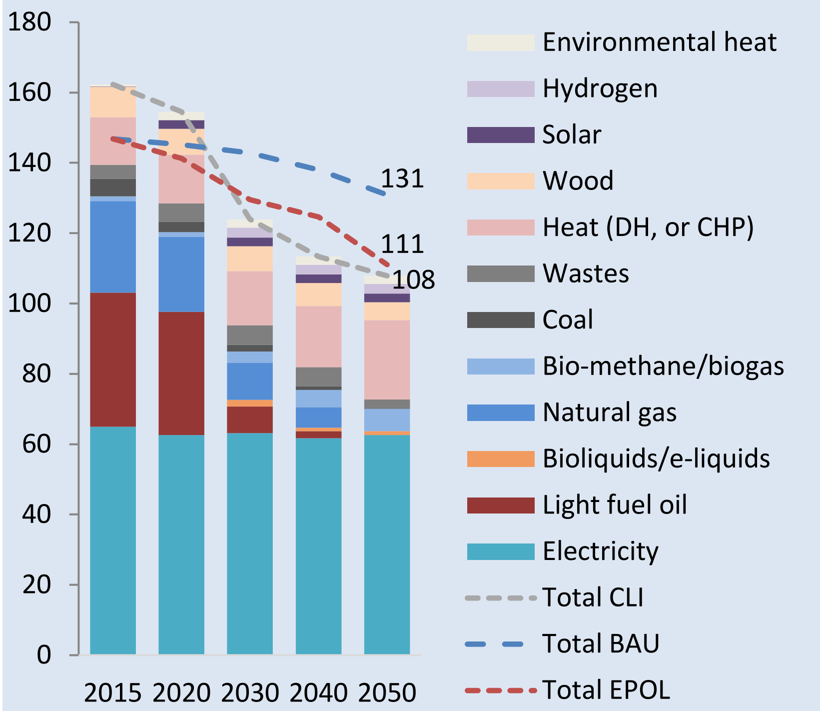
Results from BAU, EPOL and CLI scenarios

Achieving net-zero: developments on demand side

Industry (-4.5Mt)*

- Improved heat integration & savings
- CHP and district heat (incl. hydrogen)
- CO_2 capture related to cement production
- The speed of penetration of technologies is critical
- Available & reliable alterantive fuel supply is needed

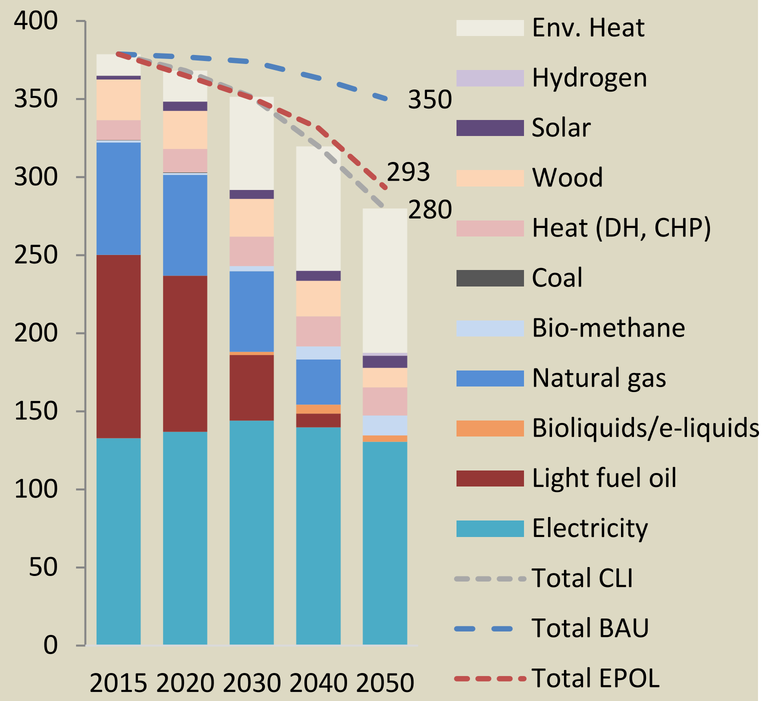
Final energy consumption PJ/yr.



Residential & Services (-13Mt)*

- Building insulation & standards
- 6x more heat provided by heat pumps
- Efficient electric appliances (eco-standards)
- The speed of transformation critical to avoid lock-ins in carbon intensive heating

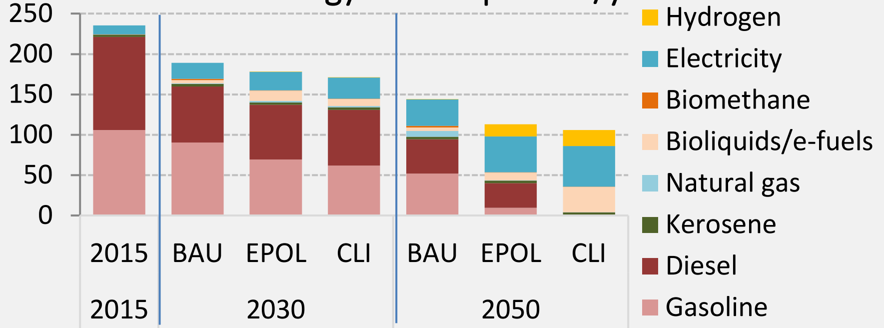
Final energy consumption PJ/yr.



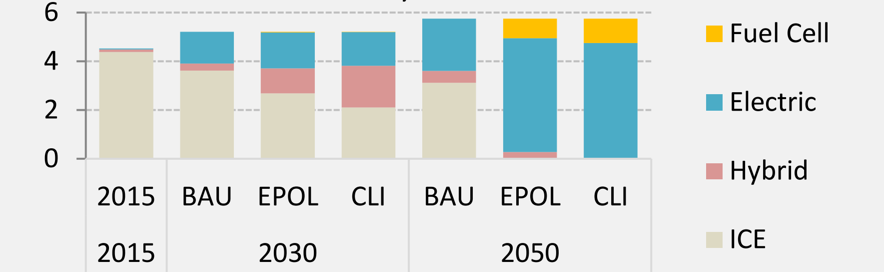
Transport sector (-16 Mt)*

- Transition period until 2030 with many options competing
- Electrification in 2030-2040, rise of fuel cells in 2050
- Private cars in 2050: 4 out of 5 electric
- Heavy trucks in 2050: 33% H2, 57% efuels/biofuels, 10% EV

Final energy consumption PJ/yr.



Private cars stock, million vehicles



PSI quantified Swiss energy sector long-term developments with the Swiss TIMES energy systems model for SCCER Joint Activity Scenarios and Modelling (SCCER JASM)
Dedicated mobility studies are performed with STEM in SCCER Mobility
Source: Panos et al. (2020)
Results from BAU, EPOL and CLI scenarios

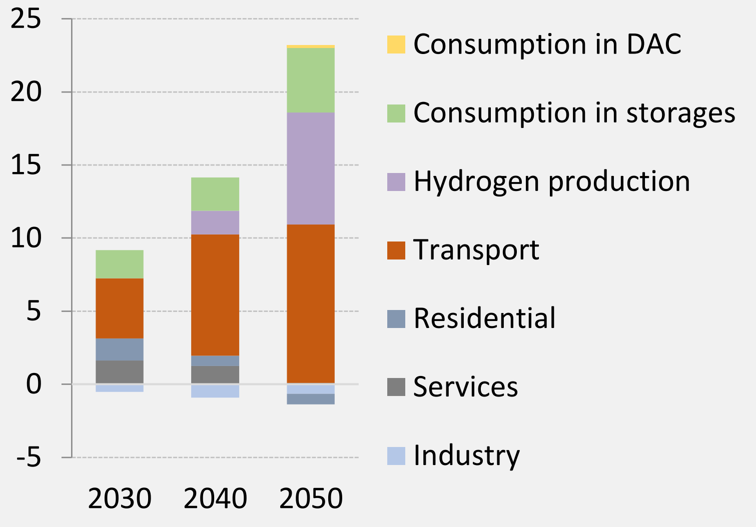
* In brackets changes of CO_2 emissions 2015-2050
* Bioliquids

Achieving net-zero: electricity supply mix

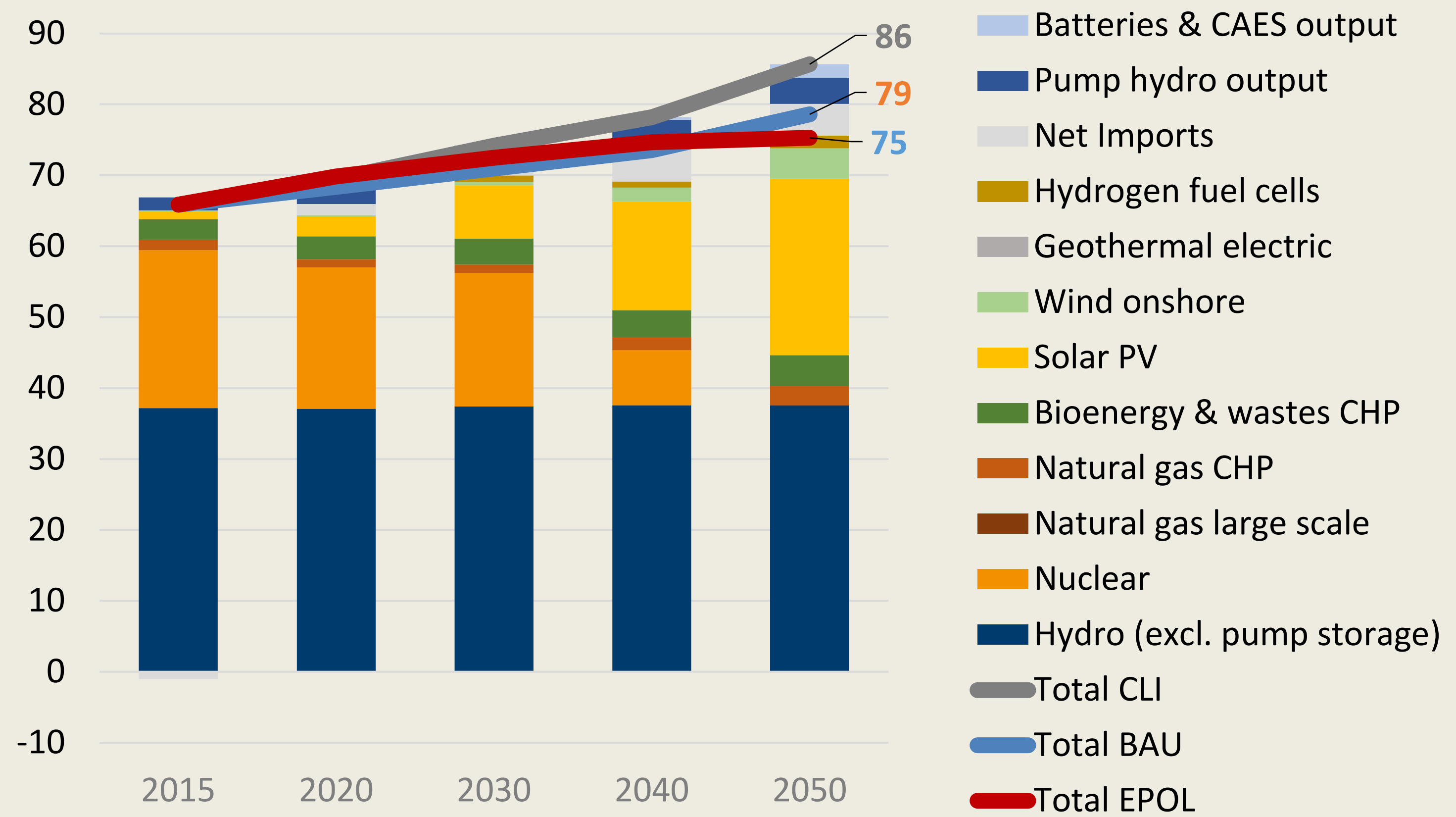
Electricity demand (+22 TWh from 2015)

- Electricity demand in stationary sectors saturates due to effiecency measures
- Transport drives electricity consumption in end-use
- Share of electricity in final energy consumption reaches 50% in 2050 (from 27% in 2015)
- New electricity uses include hydrogen production and Direct Air Capture (and increased consumption in storages)

Change in electricity consumption by sector from 2015, TWh/yr.



Electricity supply in CLI scenario and comparison with EPOL and BAU, TWh/yr.



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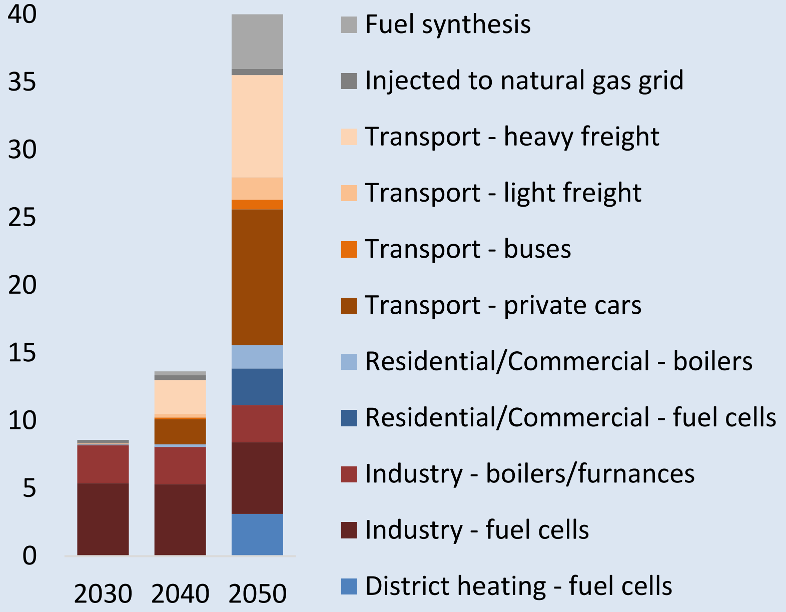
Source: Panos et al. (2020)
Results from BAU, EPOL and CLI scenarios

Achieving net-zero: the role of hydrogen

Hydrogen demand

- Industry can be the first mover
- Transport, the main hydrogen consumer in 2050
- Fuel cells vehicles call for infrastructure development, enabling penetration of hydrogen also for heating purposes
- Future success and timing of hydrogen highly depends on technological developments

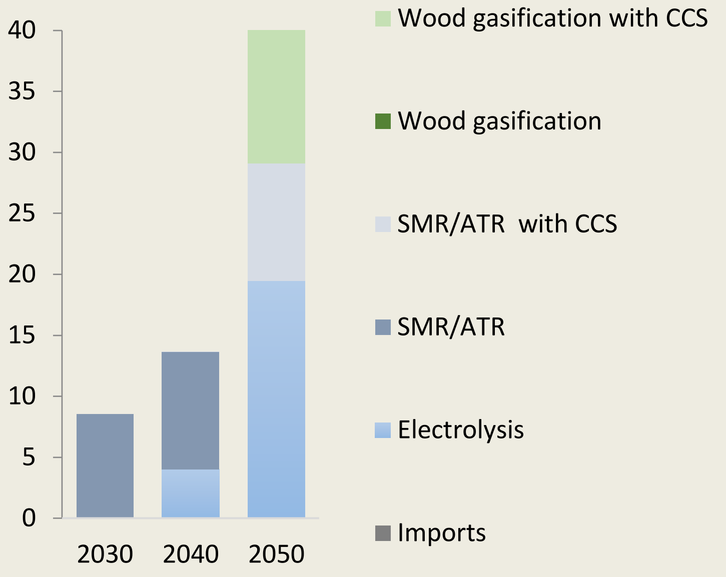
Hydrogen consumption PJ/yr.



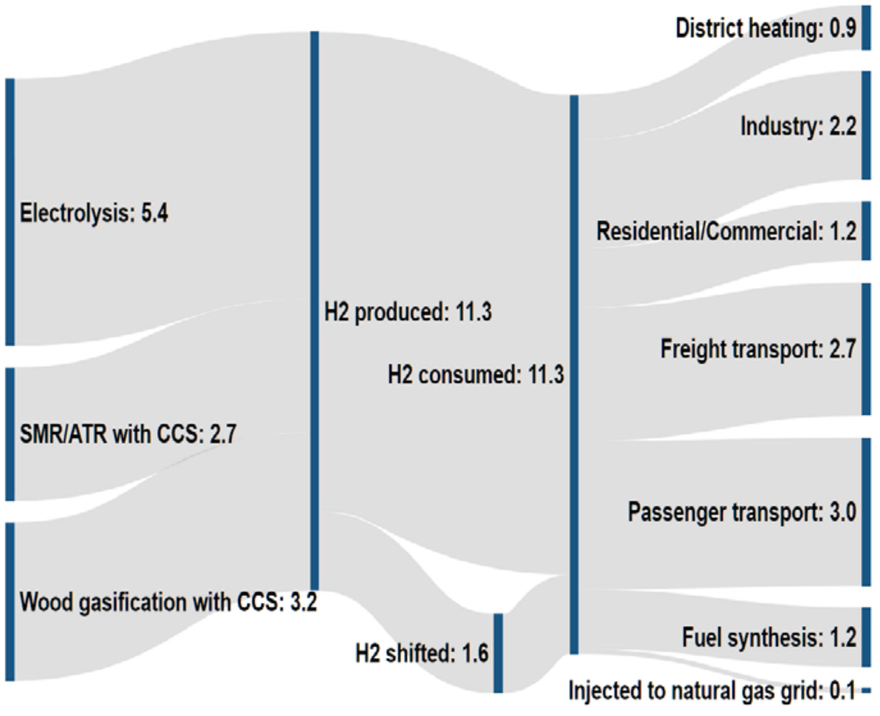
Hydrogen production

- Start building H_2 infrastructure in the 2030s
- Due to the long investment cycles, policy support should avoid stranded assets
- Climate policy instruments, a case for building H_2 infrastructure and demand, and the connection with European CO_2 and H_2 networks are essential drivers for hydrogen in Switzerland

Hydrogen production PJ/yr.



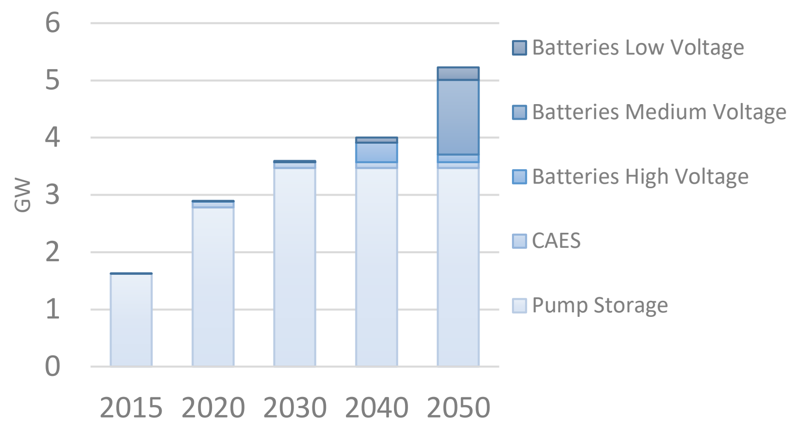
Sector coupling via hydrogen in 2050, TWh/yr.



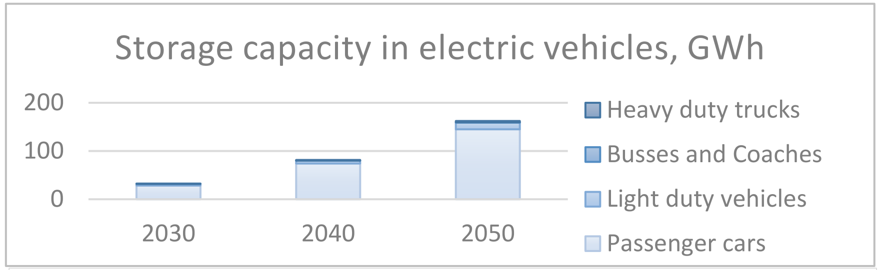
PSI quantified Swiss energy sector long-term developments with the Swiss TIMES energy systems model for SCCER Joint Activity Scenarios and Modelling (SCCER JASM)
Source: Panos et al. (2020)
Dedicated H2-related pathways assessed in ACT ELEGANCY project (Panos&Kober, 2020)
Results from BAU, EPOL and CLI scenarios

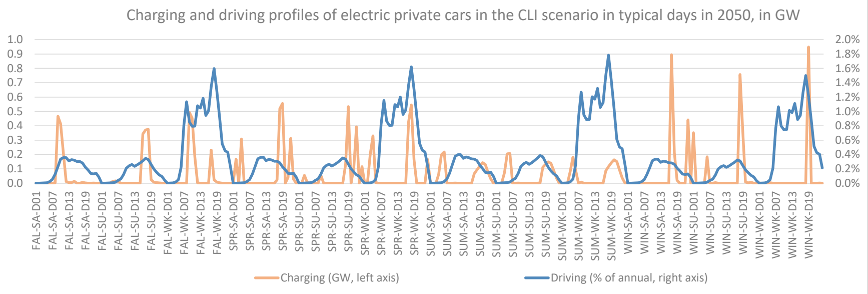
Achieving net-zero: need for flexible energy system

RES in electricity supply (electric storage at different grid levels)

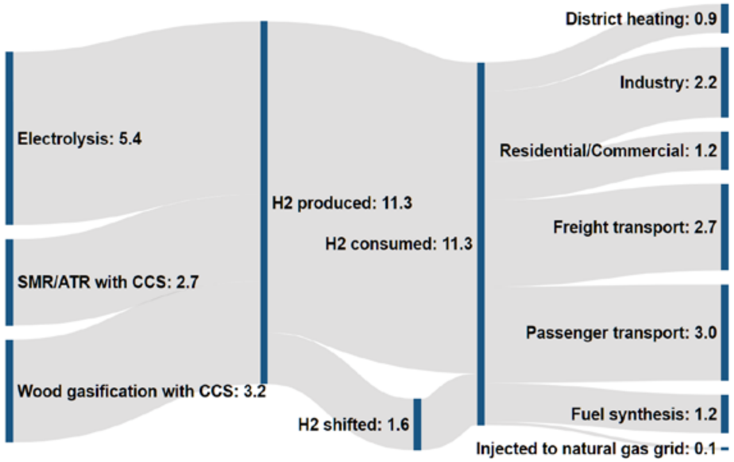


Electrified road transport (onboard batteries)

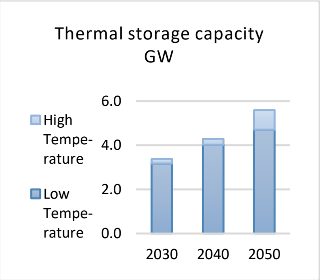


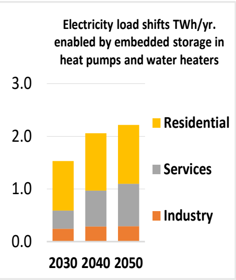


Sector coupling (seasonal storage + H2)



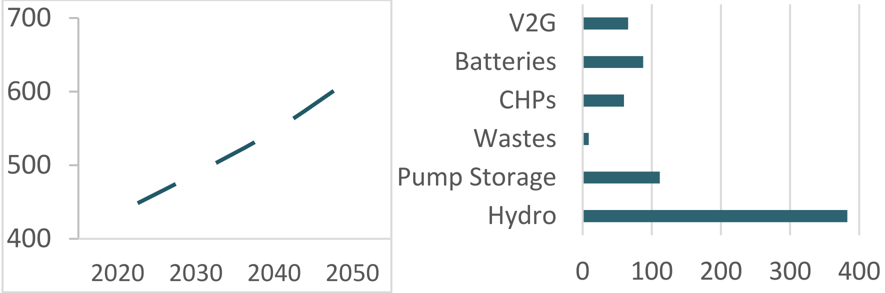
Flexible loads (incl. thermal storage)





Ancillary services markets

Maximum requirement in secondary positive reserve (left) and maximum contribution to the provision of secondary reserve by technology (right), MW



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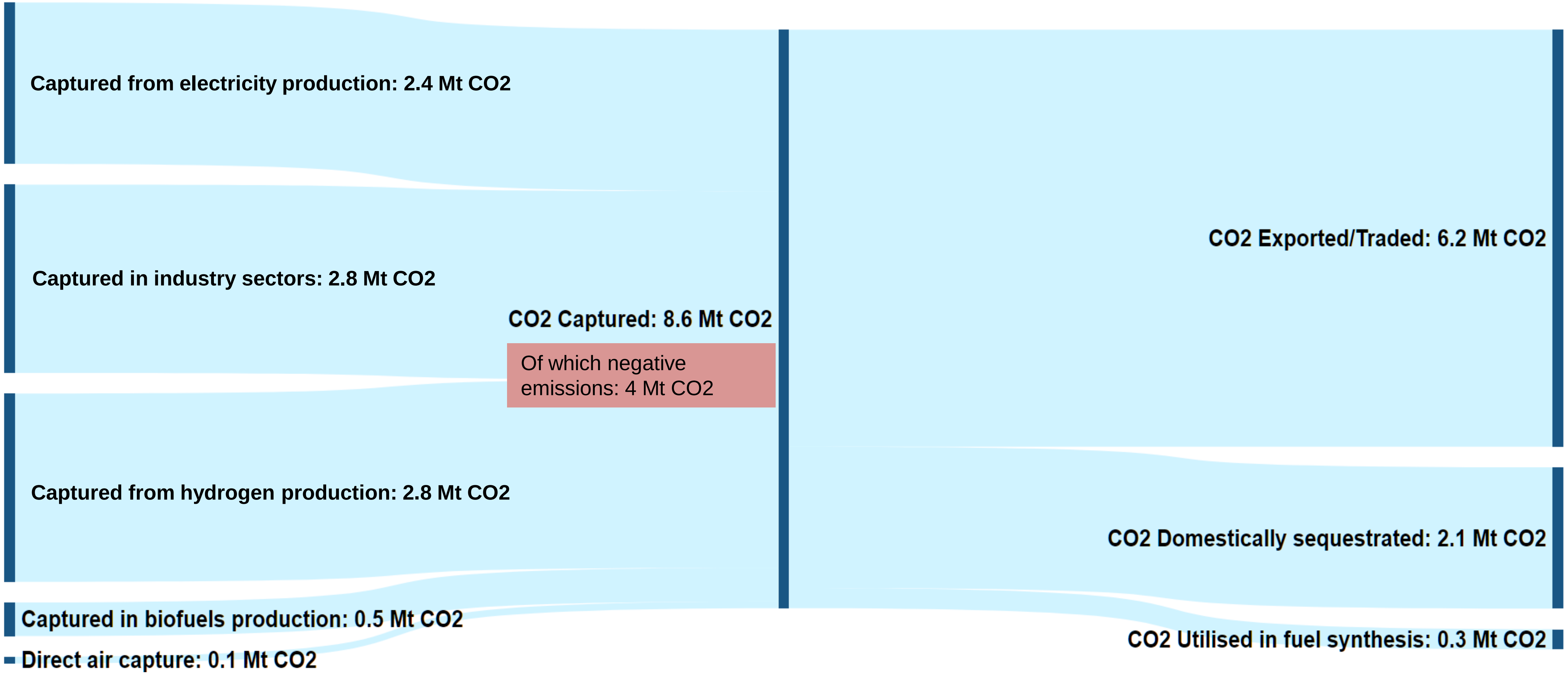
Source: Panos et al. (2020)

Results from BAU, EPOL and CLI scenarios

Achieving net-zero: CC(U)S and negative emissions (only CO_2 from the energy system is considered)

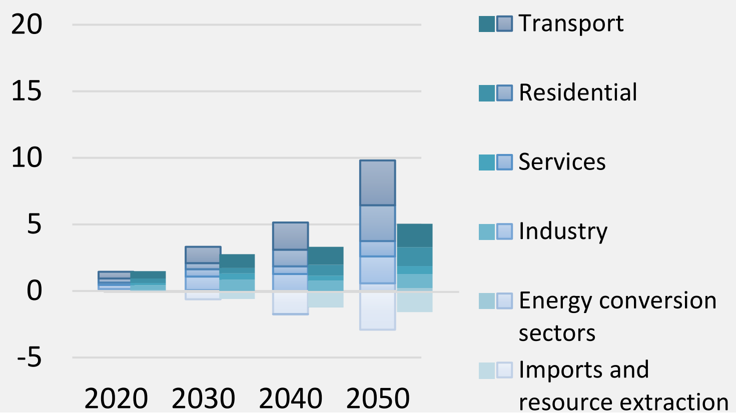


PSI quantified Swiss energy sector long-term developments with the Swiss TIMES energy systems model for SCCER Joint Activity Scenarios and Modelling (SCCER JASM)
Source: Panos et al. (2020)
Results from BAU, EPOL and CLI scenarios

Achieving net-zero: Transition costs

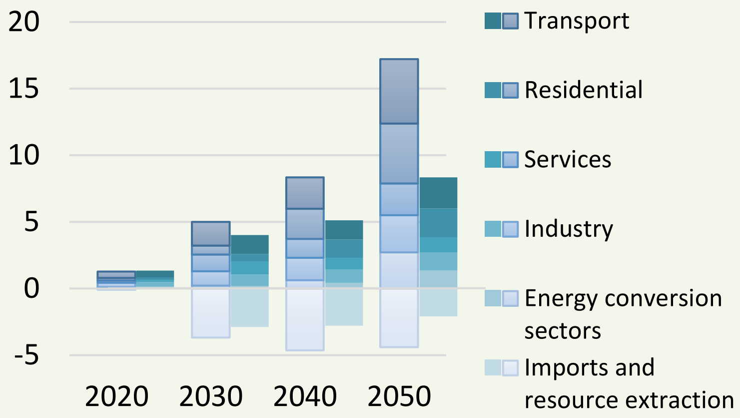
EPOL – BAU annual transition costs (undiscounted and discounted at 2.5% in billion CHF2010/yr.)

The transition costs are calculated as the difference between EPOL and BAU scenarios:
- Transition costs show a shift to capital cost
- Gains due to less expenditures in imported fuels
- The per capita cost is on average about 360 CHF/yr. undiscounted or 220 CHF/yr discounted at 2.5% for the period of 2020 – 2050*
- The electricity consumption restriction in EPOL imposes cost inefficiencies in the transition

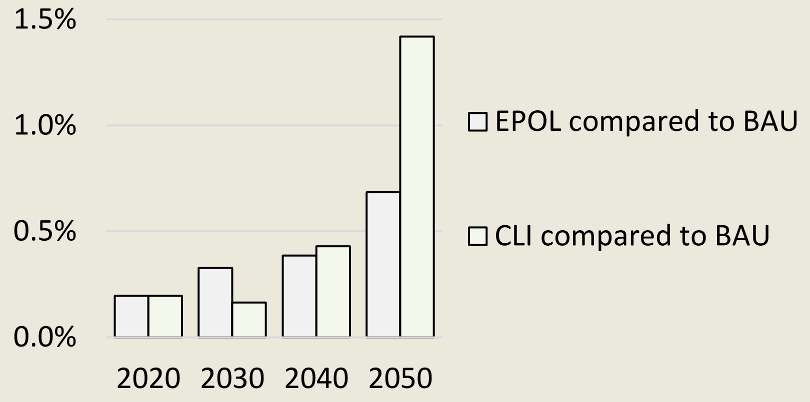


CLI – BAU annual transition costs (undiscounted and discounted at 2.5% in billion CHF2010/yr.)

The transition costs are calculated as the difference between CLI and BAU scenarios:
- Further increase of costs in the last decade
- Additional gains due to less imports
- The per capita cost is on average about 480 CHF/yr. undiscounted or 260 CHF/yr. discounted at 2.5% for the period of 2020-2050*



Energy System Transition costs as % of GDP



Some notes on the costs:
1. Energy system costs include capital costs, energy purchase costs and direct efficiency investment costs. No disutility costs are included
2. The policy costs are relative to the baseline scenario. An optimistic baseline induces less policy costs than a pessimistic one.
3. The energy system costs are also sensitive to technology developments and availability
4. STEM only accounts for the energy system, thus no tax recycling or other economic benefits are considered.
5. No local conditions are considered in STEM which could incur additional costs

* The average per capita cost is calculated as the (un)discounted cumulative difference of the costs of the scenario in focus minus the cost of the BAU scenario over the period of 2020-2050, divided by the population in 2050. When discounting, the basis year is 2020.

PSI quantified Swiss energy sector long-term developments with the Swiss TIMES energy systems model for SCCER Joint Activity Scenarios and Modelling (SCCER JASM)
Source: Panos et al. (2020)
Results from BAU, EPOL and CLI scenarios

Conclusions

- Achieving net-zero emissions in 2050 will rest on 3 pillars:
  - Encouraging low-carbon energy consumption and efficiency improvement
  - Scaling up (technically proven) technology such as renewables, battery storage, P2X, CC(U)S, electromobility
  - Implementing policy changes, as no single policy solution works for everyone

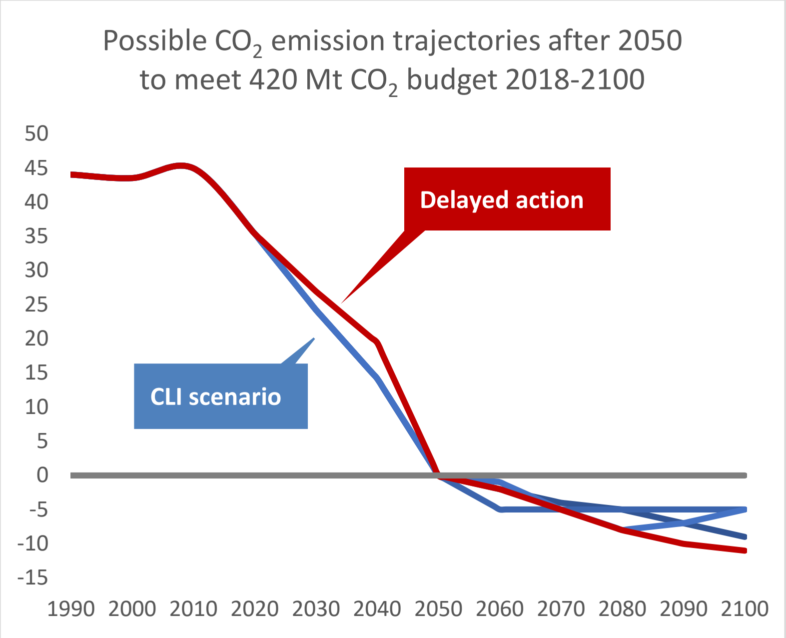
There is more to go beyond 2050:

- The net-zero in 2050 is not the ultimate target, as to respect the CO_2 budget net negative emissions would need to be achieved afterwards

- "The 2015 Paris Agreement imposes an acute and difficult policy challenge, as meeting the targets either means a very rapid immediate decarbonisation with limited NETs or accepting risks associated with pathways relying greatly on NETs", (Rogelj et al., 2019)

- "Open discussion of negative emissions is urgently needed" (van Vuuren et al., 2017)

- "The per capita impact of 'no action' on global GDP is -30% as of 2100, compared to -8% for 1.5°C of warming" (Burke et al., 2018)



* The CO_2 budget of 420 Mt CO_2 is estimated from the global remaining budget 2018-2100 of 420 Gt CO_2 to achieve 1.5°C (IPCC, 2018) , and following an egalitarian approach assuming 10 billion people in World and 10 million people in Switzerland

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Thank you very much for your attention

My thanks for their support go to:
Dr. Tom Kober
Mr. Kannan Ramachandran
Dr. Martin Densing
Dr. Stefan Hirschberg

Evangelos Panos, evangelos.panos@psi.ch
02.11.2020

In cooperation with the CTI

Energy funding programme
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