“CO_2 neutrale Schweiz: Elektrizität, Wasserstoff und syn. Kohlenwsserstoffe”

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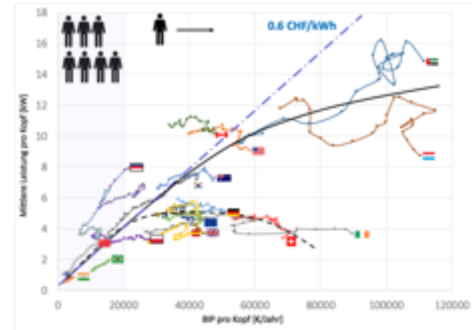
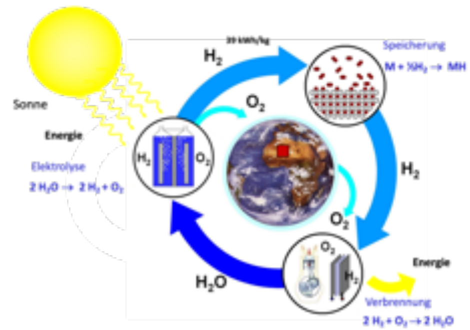
Parlamentarischen Gruppe
Wasserstoff/Power-to-X
Bern, 5. März 2024

CO_2 neutrale Schweiz: Elektrizität, Wasserstoff und P2X

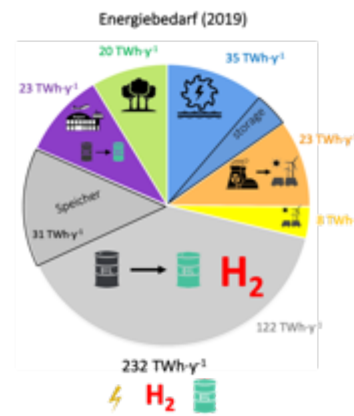


1) Globale Entwicklung

2) Wasserstoff, syn. Kohlenwasserstoffe

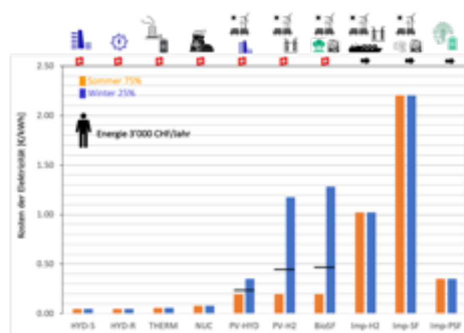


3) Energiewende

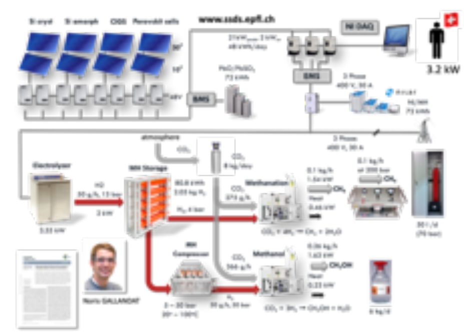


4) Lösungen

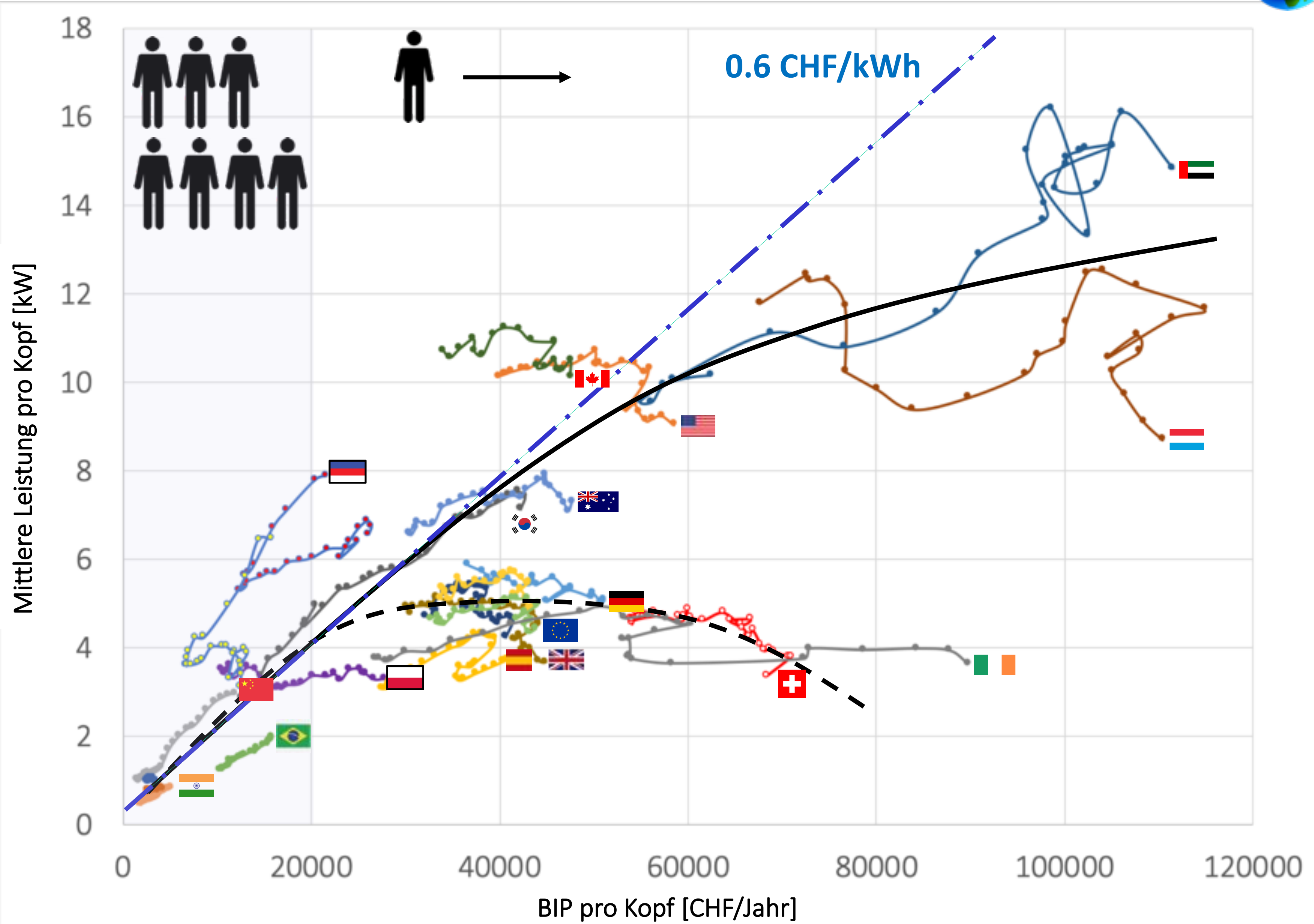
5) Kosten



6) Optionen

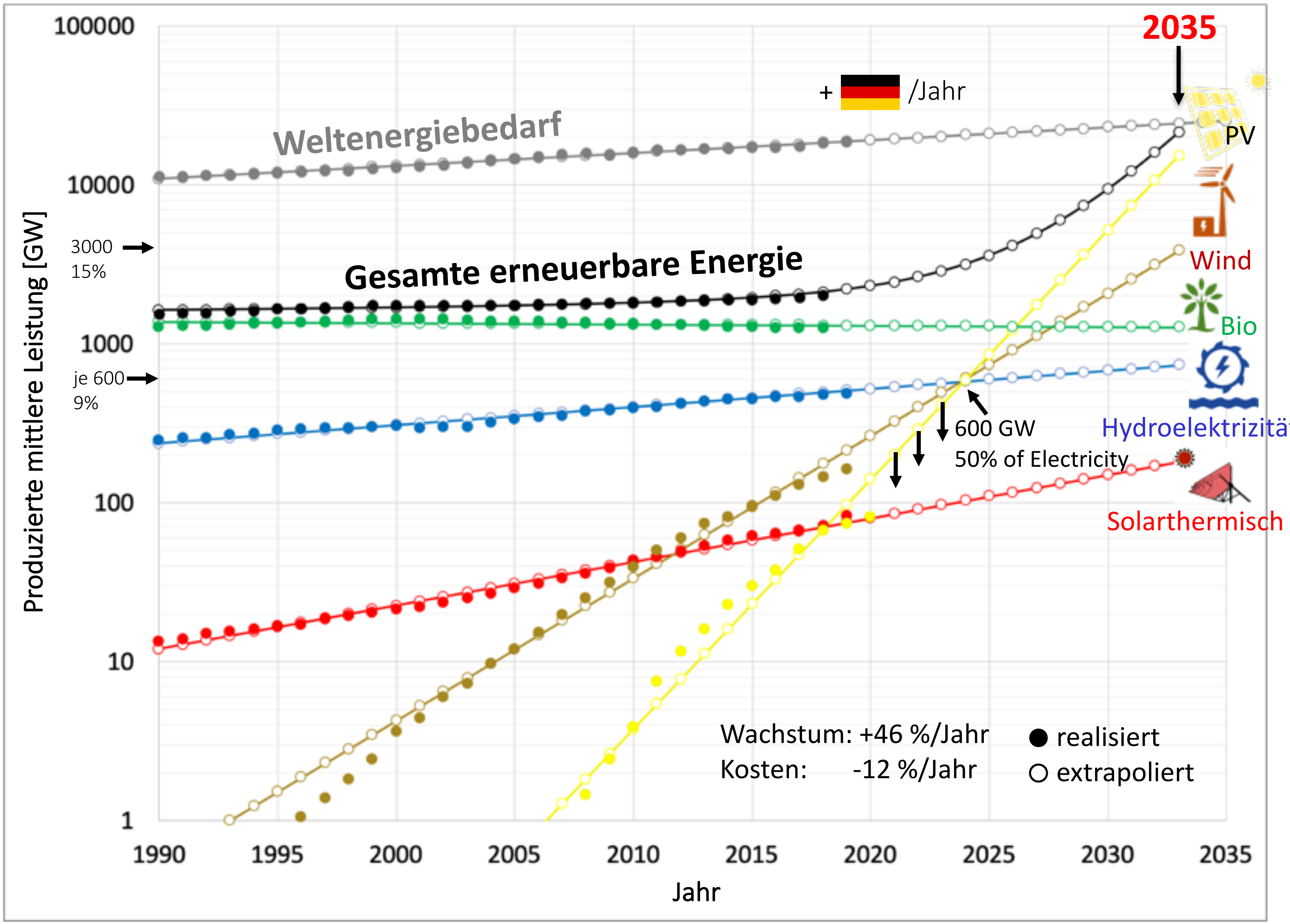


Energie und Wirtschaft



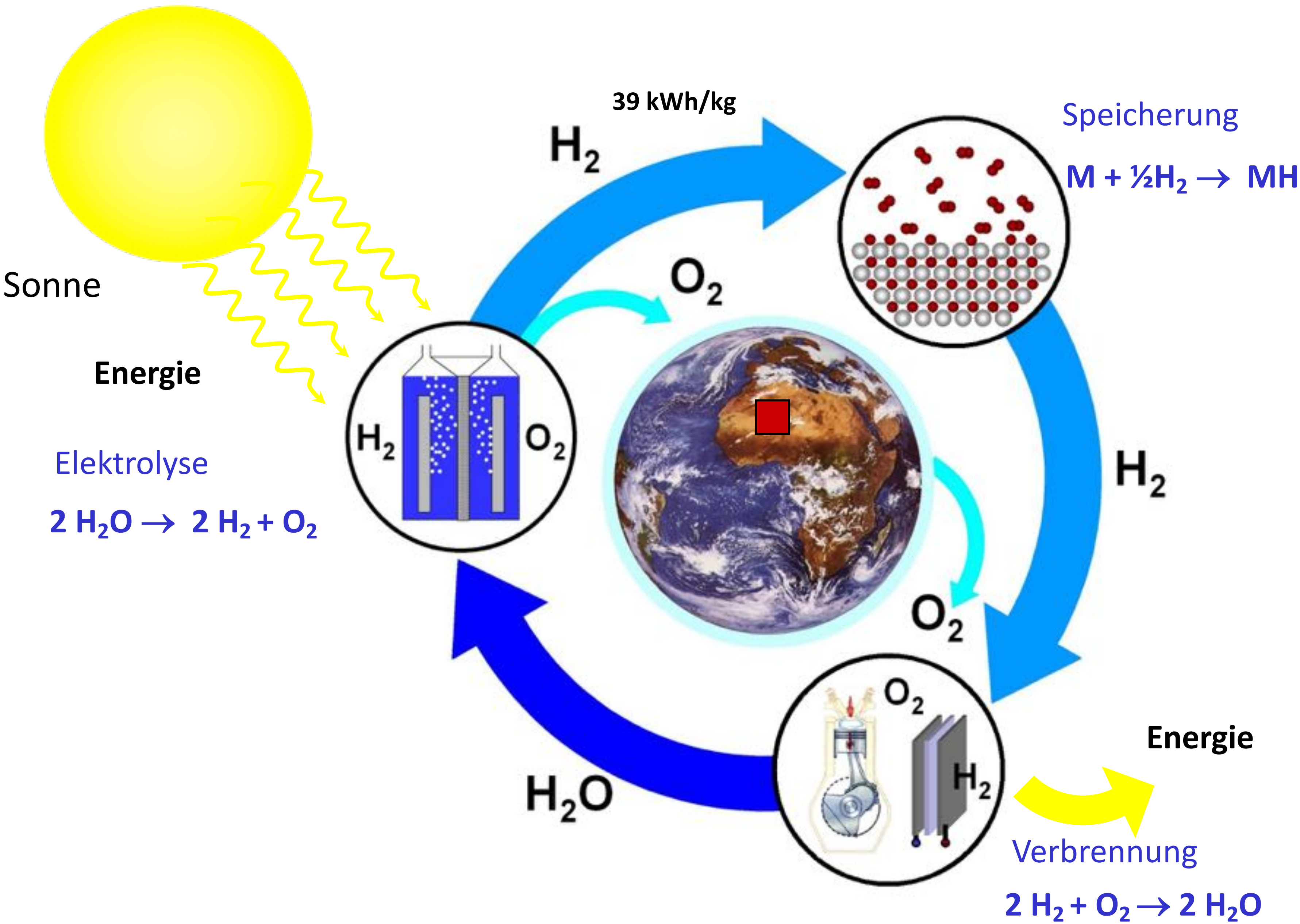
Ref.: https://ourworldindata.org/grapher/energy-use-per-capita-vs-gdp-per-capita

Globale erneuerbare Energieproduktion

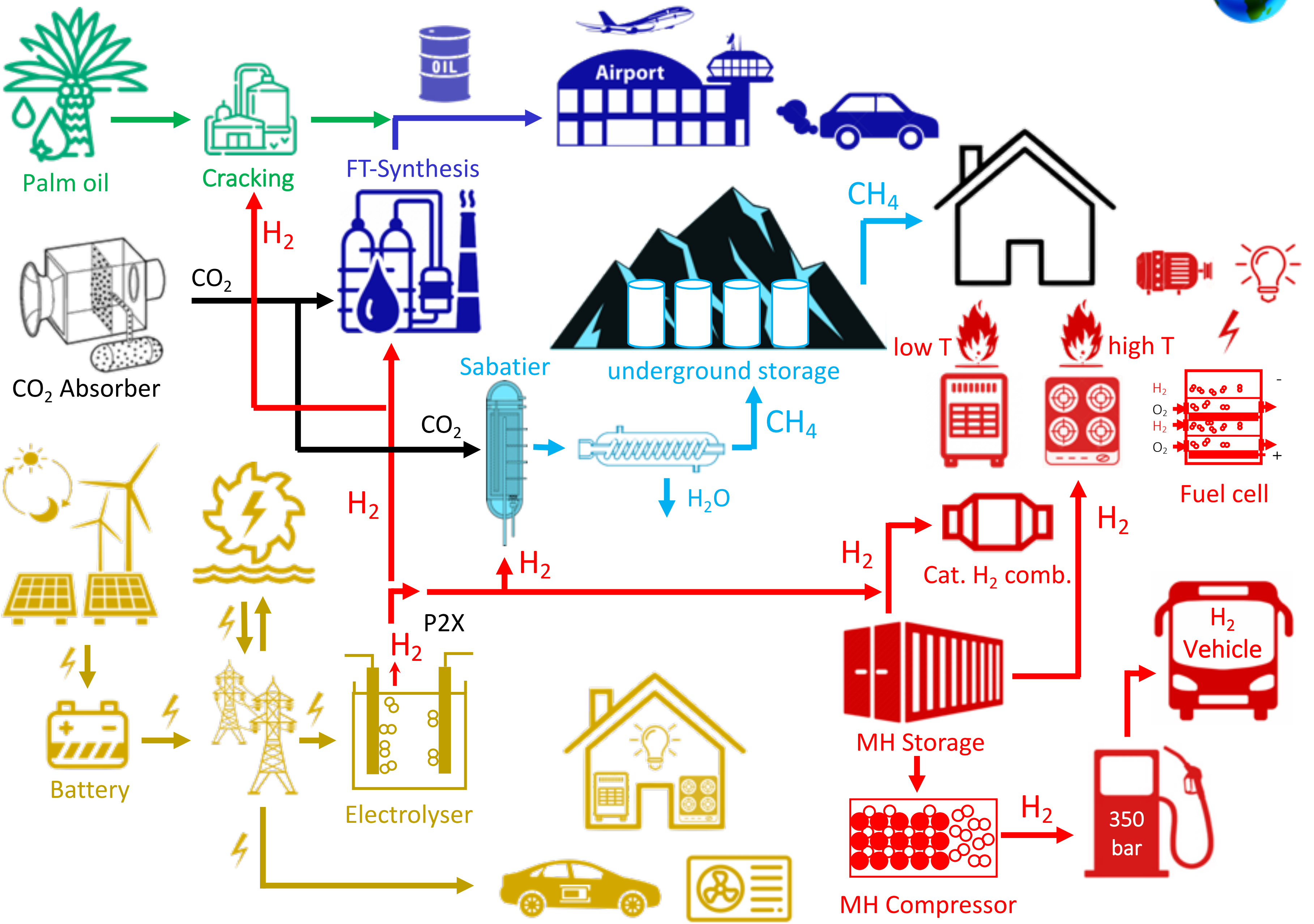


Ref.: https://ourworldindata.org/energy. https://www.pv-magazine.com/2023/02/16/global-solar-installations-may-hit-350-6-gw-in-2023-says-trendforce/#:~:text=2022, and https://ourworldindata.org/energy

Wasserstoff Kreislauf



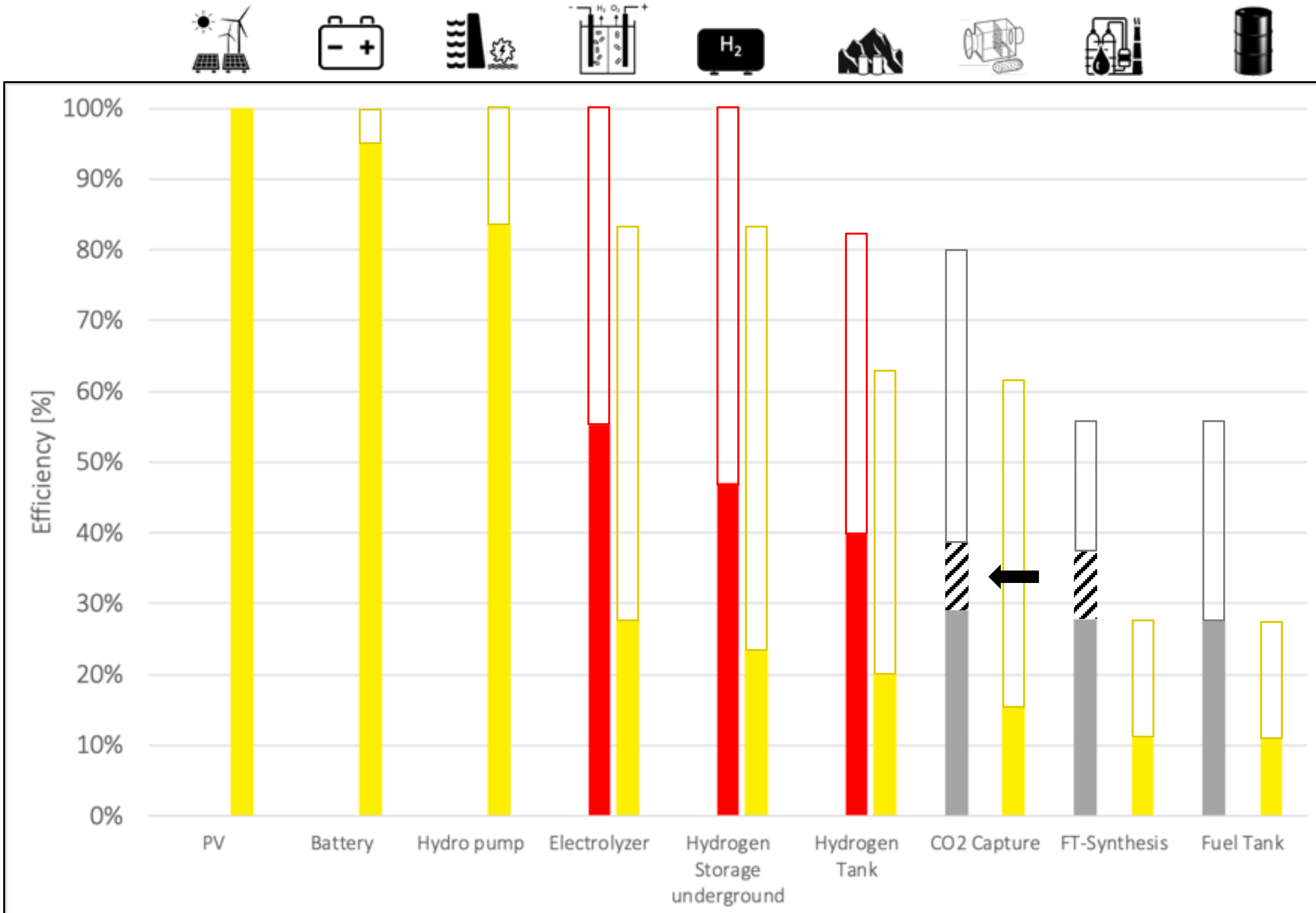
Erneuerbare Energiesysteme



CO_2 neutrale Schweiz

Effizienz entlang der Energiewandlung

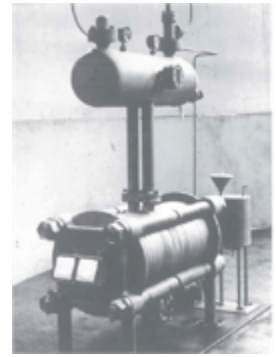
Power to X (P2X)



Schweizer Wasserstoff Entwicklungen

Erster H_2 Motor 1807
Francois Isaac de Rivaz

Wasserkraftwerkt Gampel 1898



Elektrolyseur
Ewald Zdansky 1949

Alkalische Elektrolyseur 4MW, 1980
Giovanola, Lurgi, IHT

PV, Elektrolyse, Auto, Herd
Markus Friedli 1991

Wasserstoff Speicher 1997 in Monthey

2001

Ratrac MH & ICE 2004

H_2 FC Strassenreiniger
Hy.move 2009

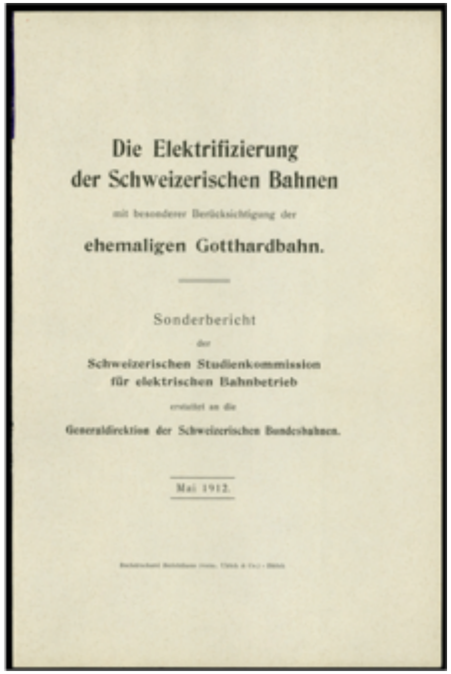
Energieautarkes Haus
René Schmid Architekten 2016

PEM Brennstoffzelle 2017

Hyundai H_2 Lastwagen
2020

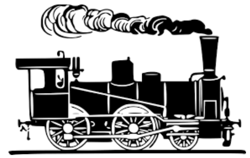
DASH MH-FC Speicher
System 2021

Energiewende in der Schweiz 1912


Die Elektrifizierung
der Schweizerischen Bahnen
mit besonderer Berücksichtigung der
ehemaligen Gotthardbahn.

Sonderbericht
der
Schweizerischen Studienkommission
für elektrischen Bahnbetrieb
erstattet an die
Generaldirektion der Schweizerischen Bundesbahnen.

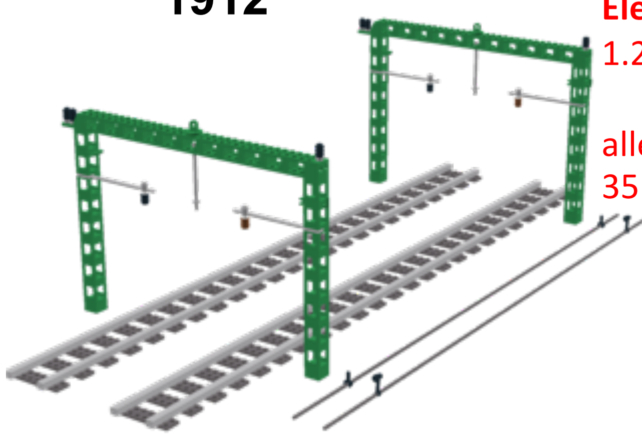
Mai 1912.



1912

Ref.: "Die Elektrifizierung der Schweizerischen Bahnen mit besonderer Berücksichtigung der ehemaligen Gotthardbahn.", Sonderbericht der Schweizerischen Studienkommission für elektrischen Bahnbetrieb erstattet an die Generaldirektion der Schweizerischen Bundesbahnen. Mai 1912.

1912



Elekrifizierung
1.23 – 2.6 Mio.€/km

alle 27m ein Mast,
35 – 70 k€ pro Mast

Schienennetz 62 Mio. €/km
(Autobahn 150 - 330 Mio.€/km)

Ref.: Deutschland: Lindau -München 500 Mio.€ für 189 km incl. Lärmschutz und neuem Bahnhof...
Dänemark: Gesamtes Schienennetz 1'600 Mio.€ für 1300 km

Energie Strategie

Fukushima Dai-ichi Kernkraftwerk Desaster


11. March 2011

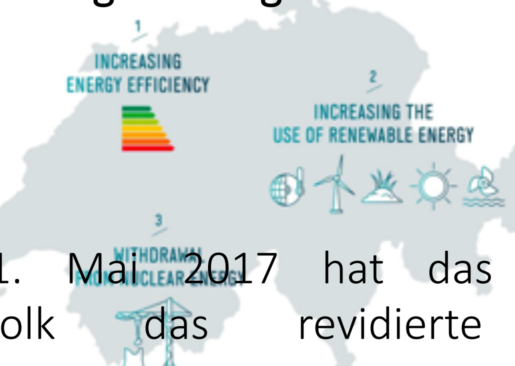

24. March 2011

11. March 2011 Erdbeben

25. Mai 2011 Der Bundesrat hat entschieden, künftig nicht mehr auf Atomkraft zu setzen. Die bestehenden Kernkraftwerke sollen so lange am Netz bleiben, wie sie sicher sind. Bestätigt durch das nationale Parlament am 8. Juni 2011.

Paris Klimaabkommen 2014

Energiestrategie Schweiz 2050



Am 21. Mai 2017 hat das Schweizer Stimmvolk das revidierte Bundes-energiegesetz angenommen. Die Ziele der Überarbeitung sind die Senkung des Energieverbrauchs, die Steigerung der Energieeffizienz und die Förderung der Nutzung erneuerbarer Energien. Zudem verbietet die überarbeitete Fassung den Bau neuer Kernkraftwerke.

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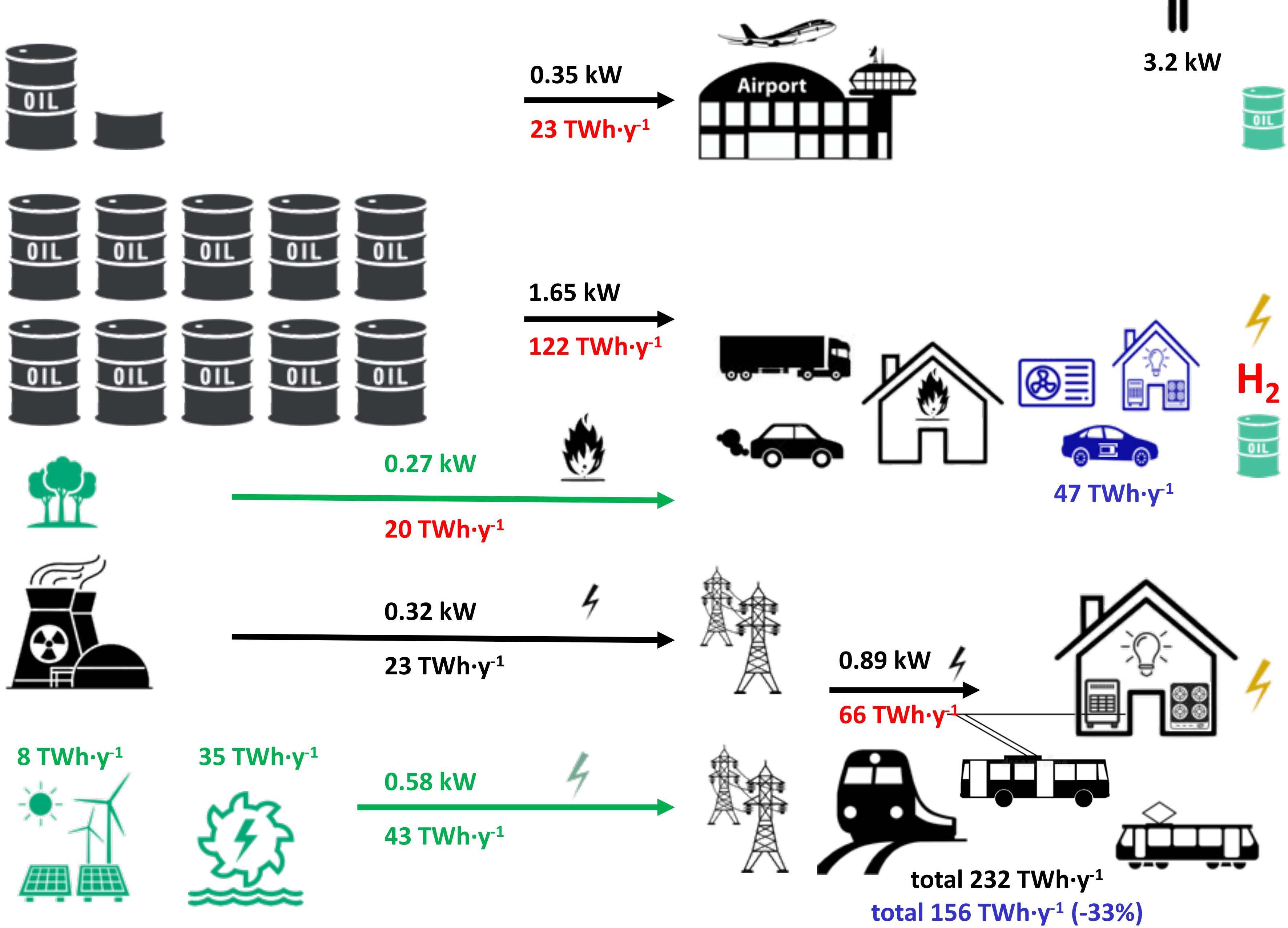
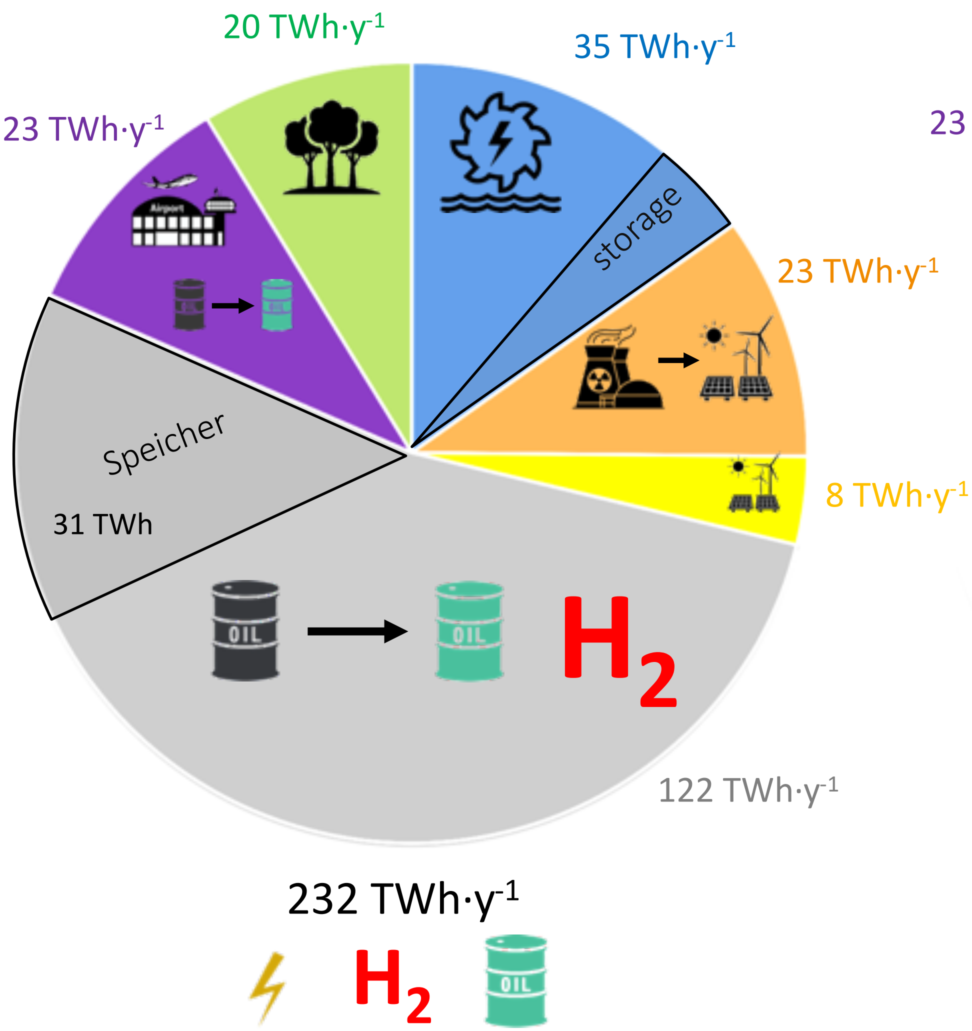
Die Schweizer Energiewirtschaft 2019

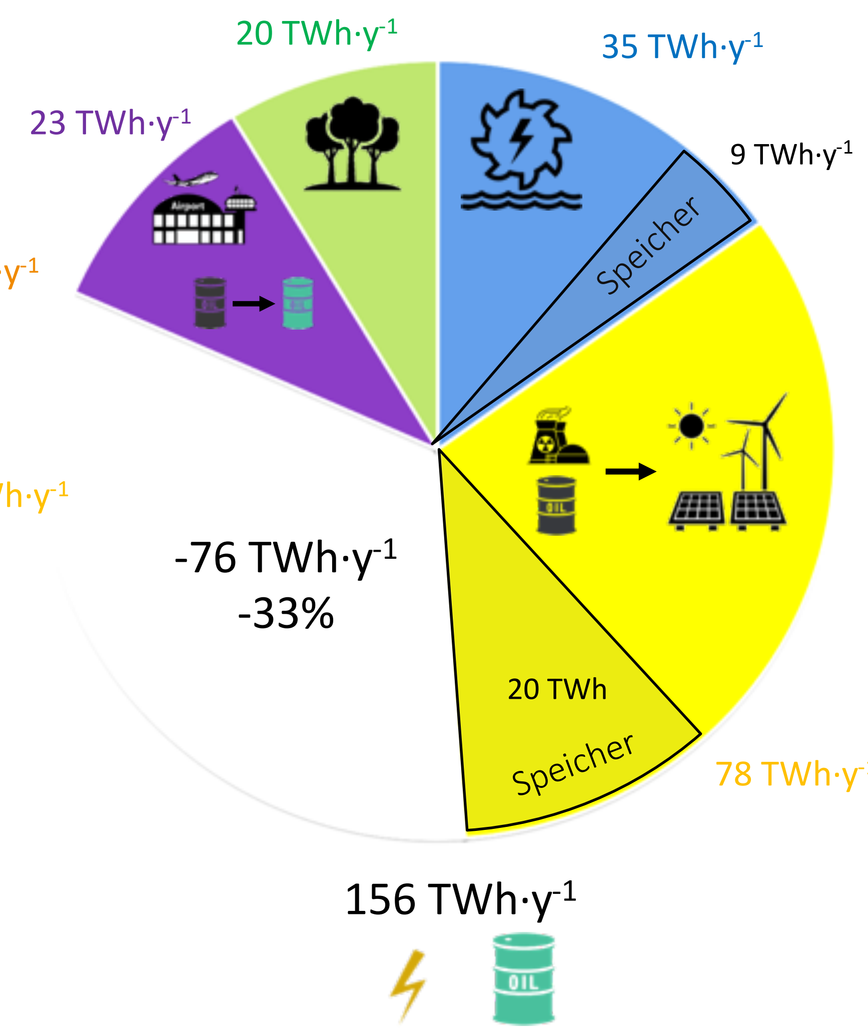


Die Schweizer Energiebedarf 2019

Energiebedarf (2019)

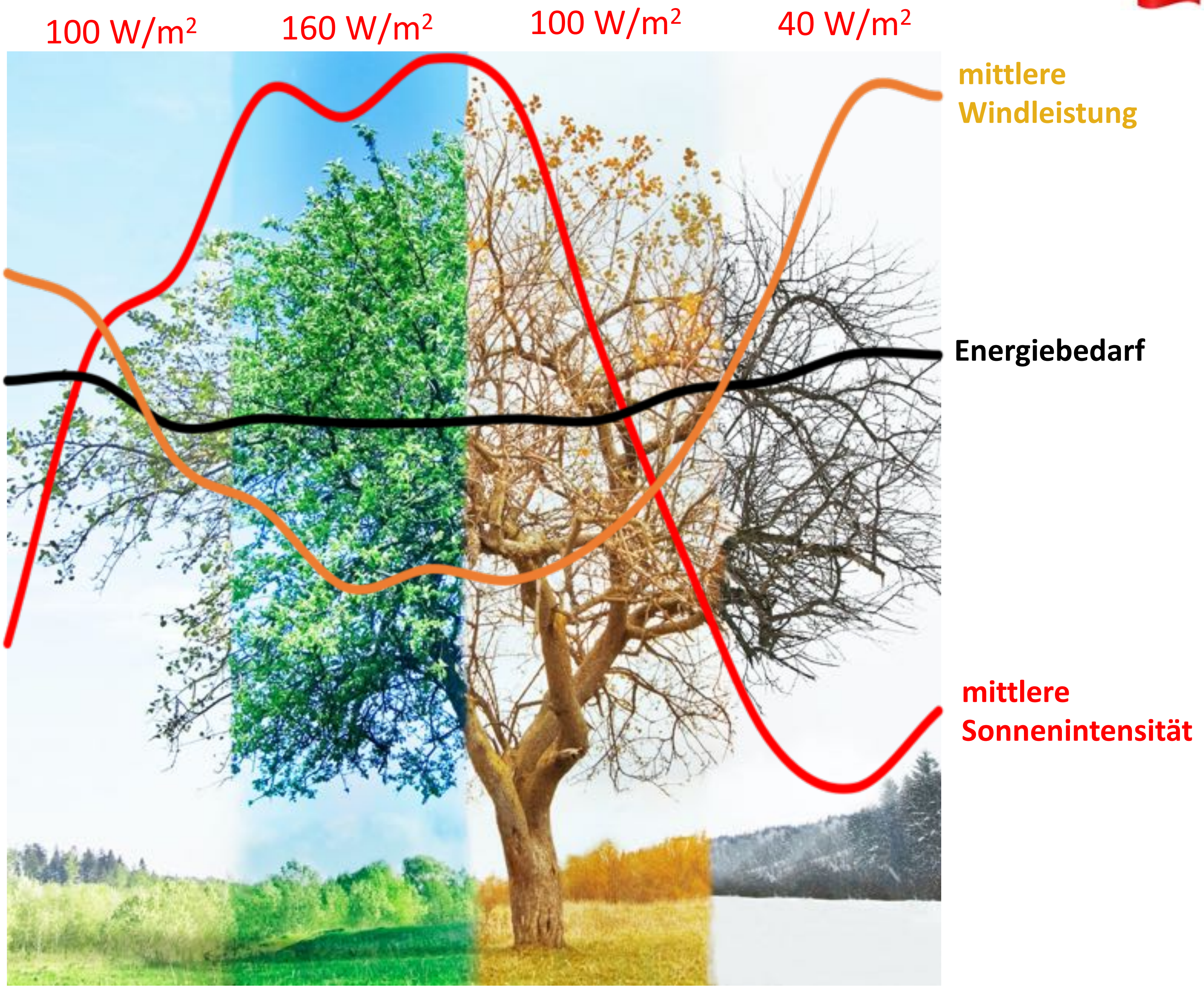


Elektrifizierung

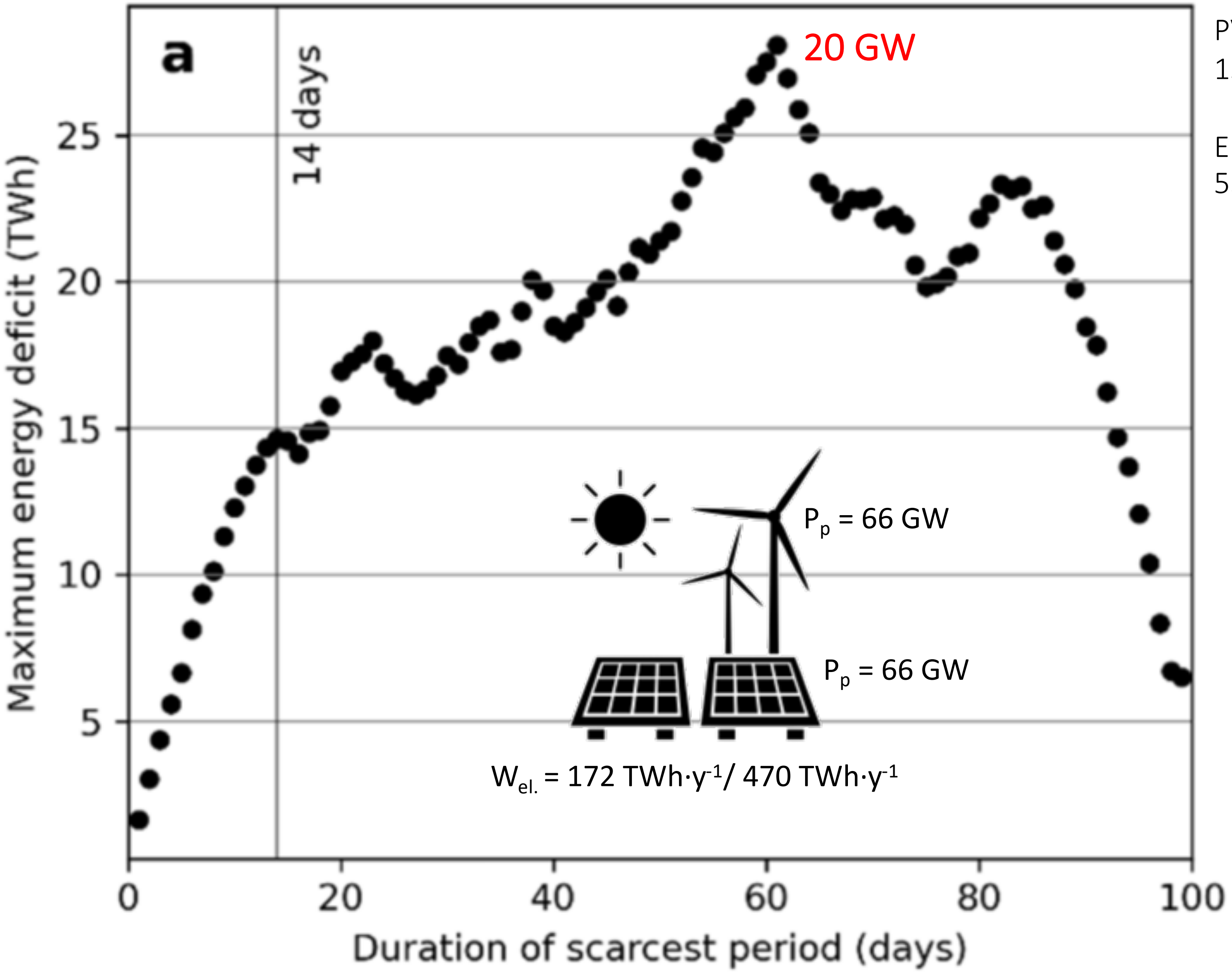


Ref.: SCHWEIZERISCHE GESAMTENERGIE STATISTIK (2019) Art.-Nr. 805.006.19 / 08.20 / 1200 / 860467013, Federal Office of Energy, Switzerland, https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/gesamtenergiestatistik.exturl.html/

Jahreszeiten



Erneuerbare Energie und Speicherung



PV & Wind:
150 GW_p installiert

Elektrizität:
53 GW mittlere Leistung

Ref.: Oliver Ruhnau, and Staffan Qvist,"Storage requirements in a 100% renewable electricity system: extreme events and inter-annual variability", Environ. Res. Lett. 17 (2022) 044018, https://doi.org/10.1088/1748-9326/ac4dc8

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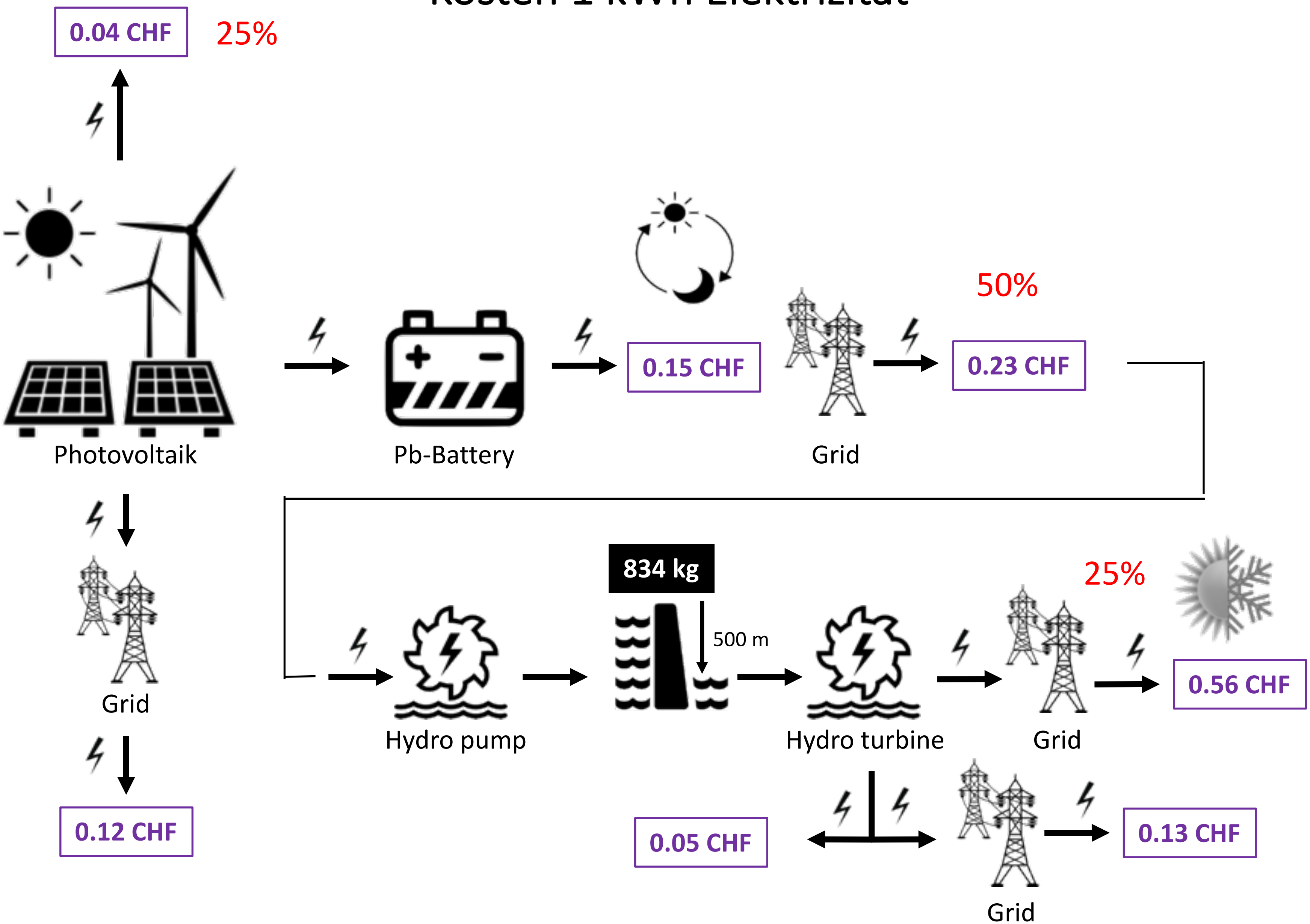
Erneuerbare Energiewirtschaft

	Elektrizität 3669.-	Wasserstoff 5683.-	Syn. Öl 9712.-
23 TWh·y⁻¹	1 x 75 GWh 316.- 4 x		
121 TWh·y⁻¹, 47 TWh·y⁻¹	2 x 134 km² 150 GWh 642.- 9 x 1.5 TWh	6 x 480 GWh 2656.- 25 x 2 Mm³ 200 bar	12 x 920 GWh 6684.- 94 Mio. 159 L
Airport 23 TWh·y⁻¹			2 x 140 GWh 1212.- 14 Mio.
existierende PV, Biomasse, Wasserkraft 63 TWh·y⁻¹	1500.- 8 TWh·y⁻¹ 20 TWh·y⁻¹ 35 TWh·y⁻¹		

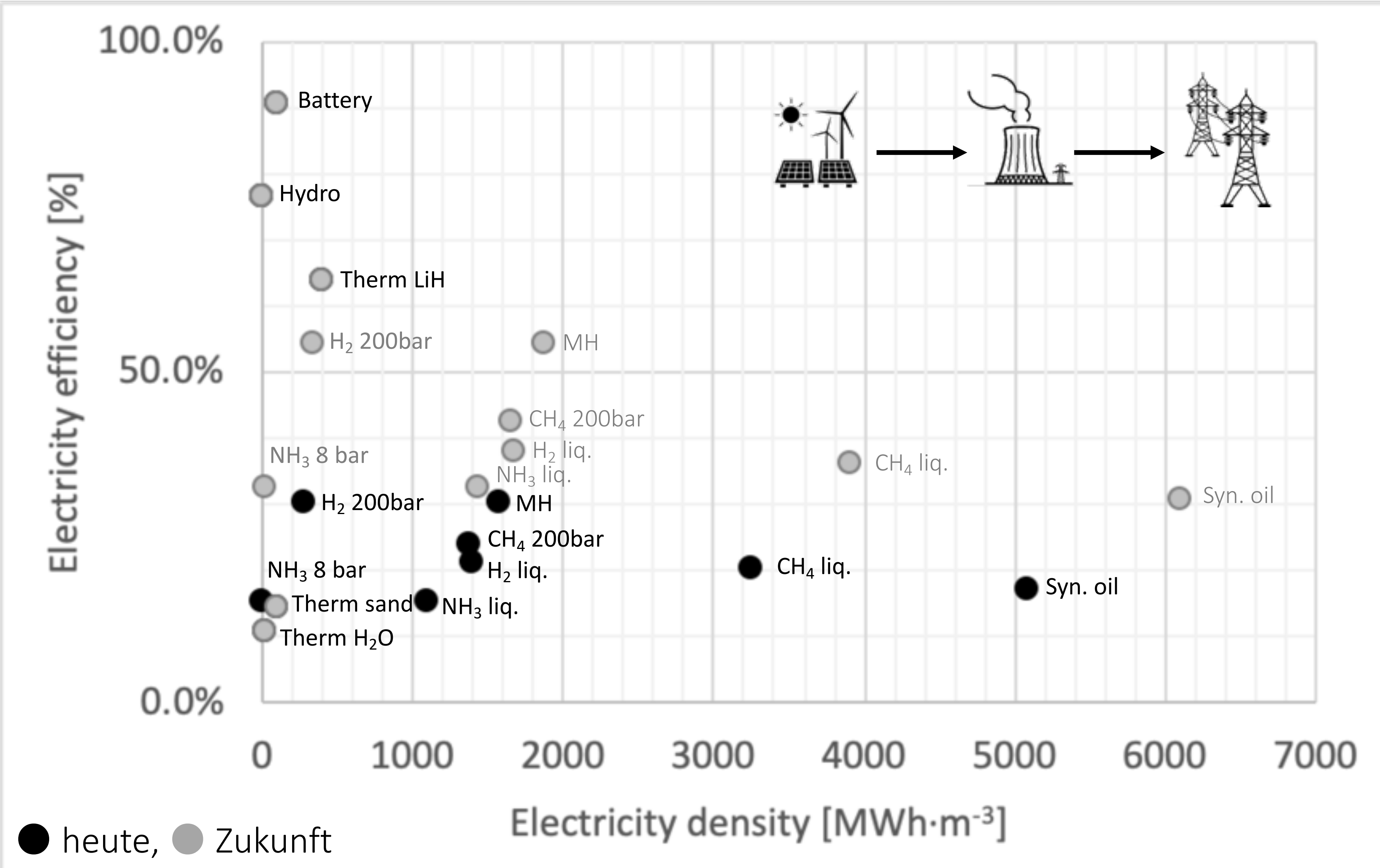
Ref.: A. ZÜTTEL, N. GALLANDAT, P. J. DYSON, L. SCHLAPBACH, P. W. GILGEN, S. ORIMO, “Future Swiss Energy Economy: the challenge of storing renewable energy”, Frontiers in Energy Research: Process and Energy Systems Engineering, 9 (2022)

Erneuerbare Energie nach Produktion und nach Bedarf

Kosten 1 kWh Elektrizität



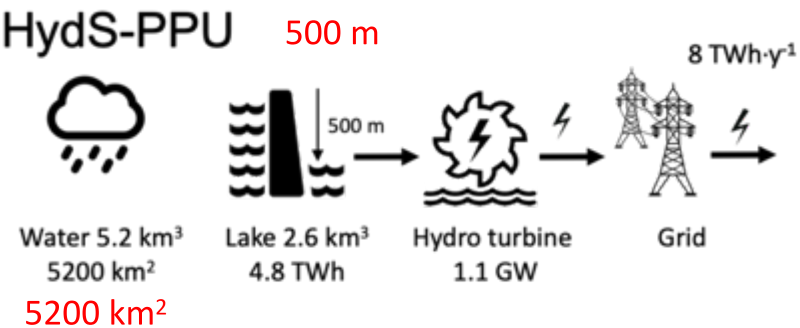
Effizienz und Speicherdichte erneuerbarer Elektrizität



Erneuerbare Energie nach Bedarf
Kraftwerkseinheiten 1GW

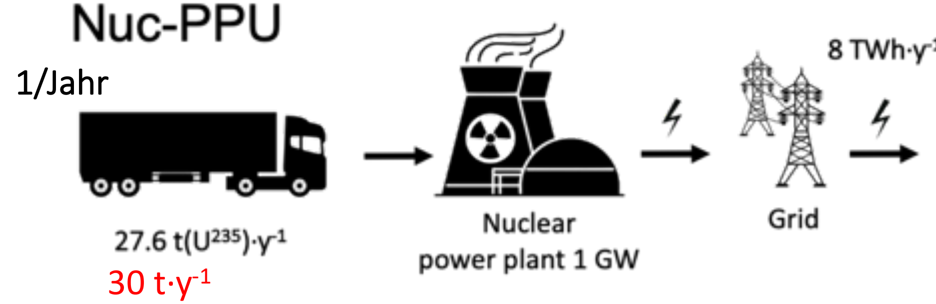
Wasserkraft

HydS-PPU

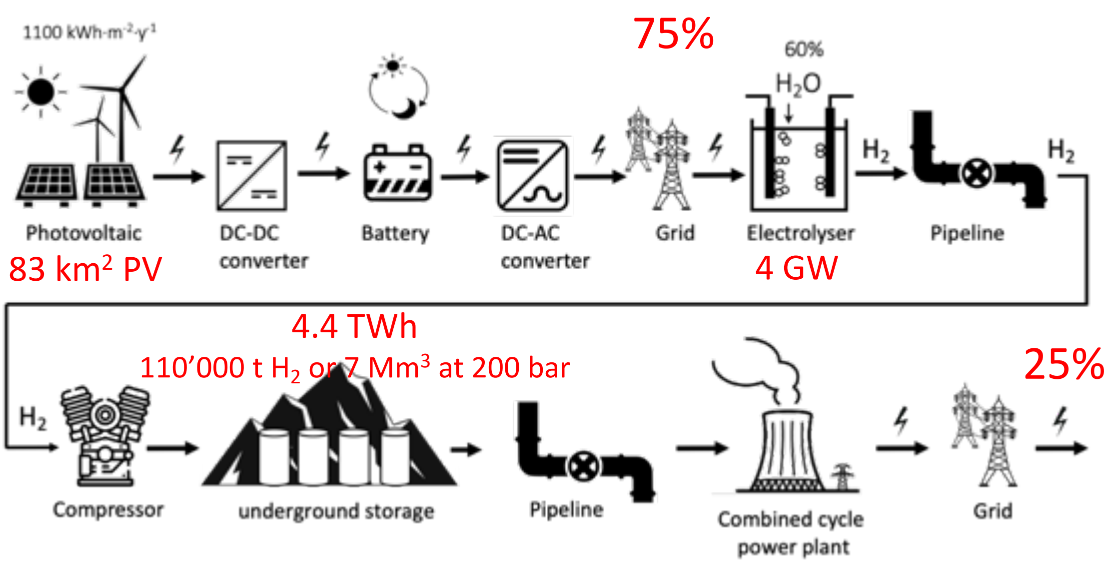


Thermische Kraftwerke

Nuc-PPU



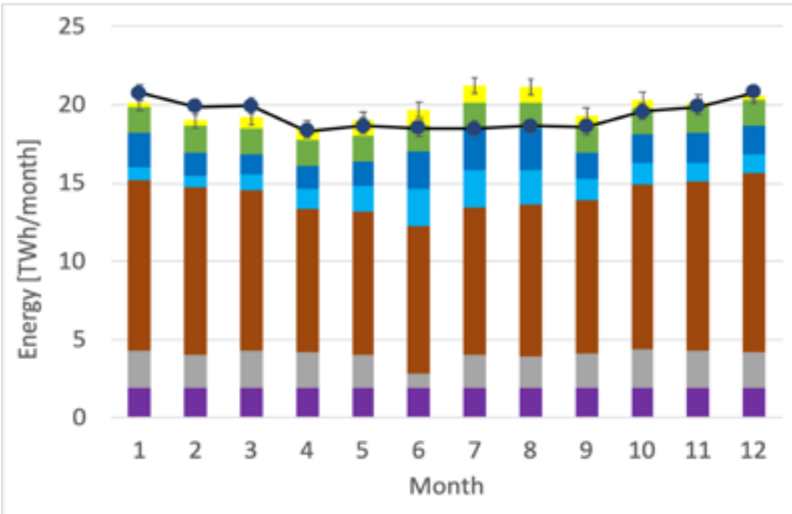
PV, Windturbine



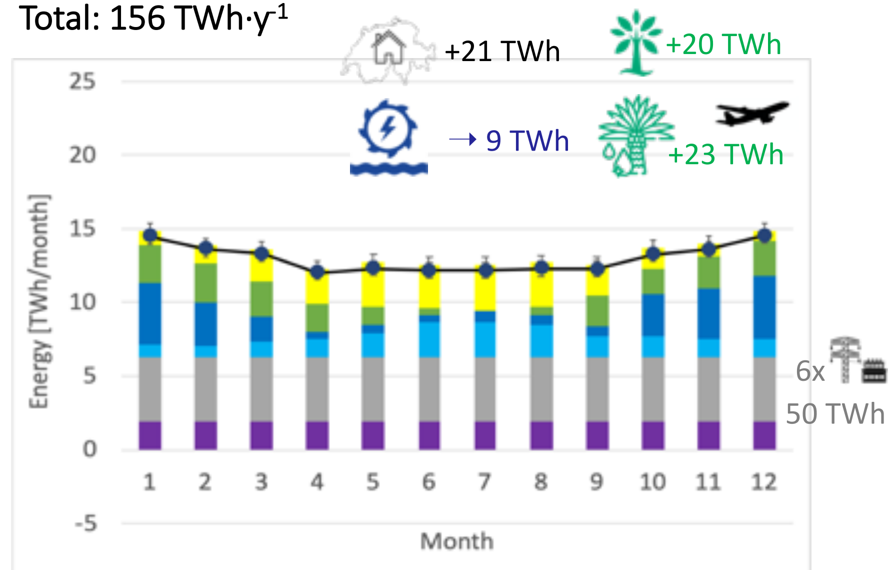
CO_2 neutrale Schweiz

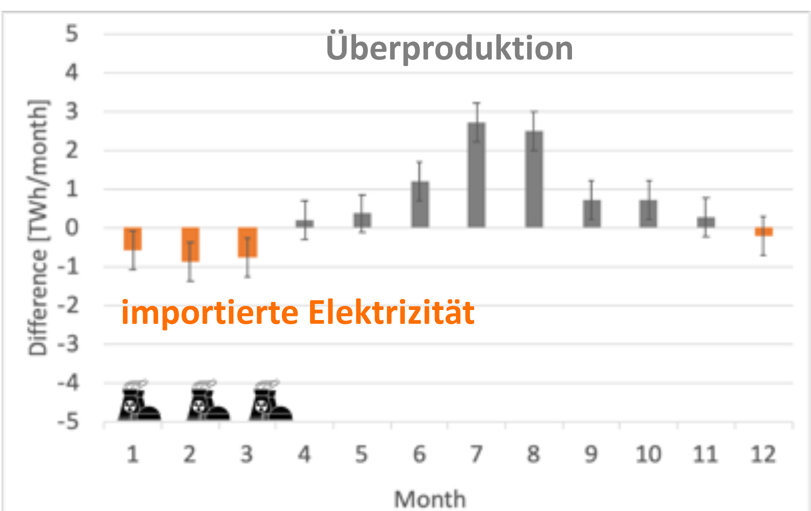
Substitution fossiler mit erneuerbare Energie

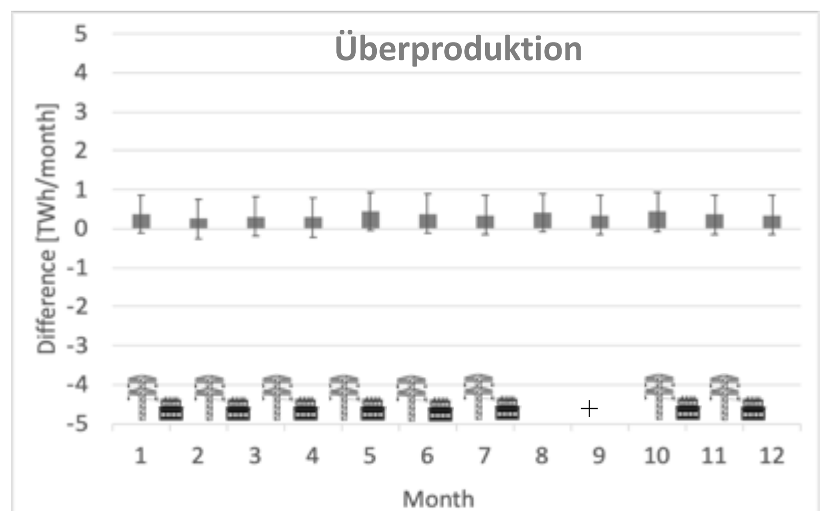
Total: 232 TWh·y^{-1} Fossil: 122 TWh·y^{-1}



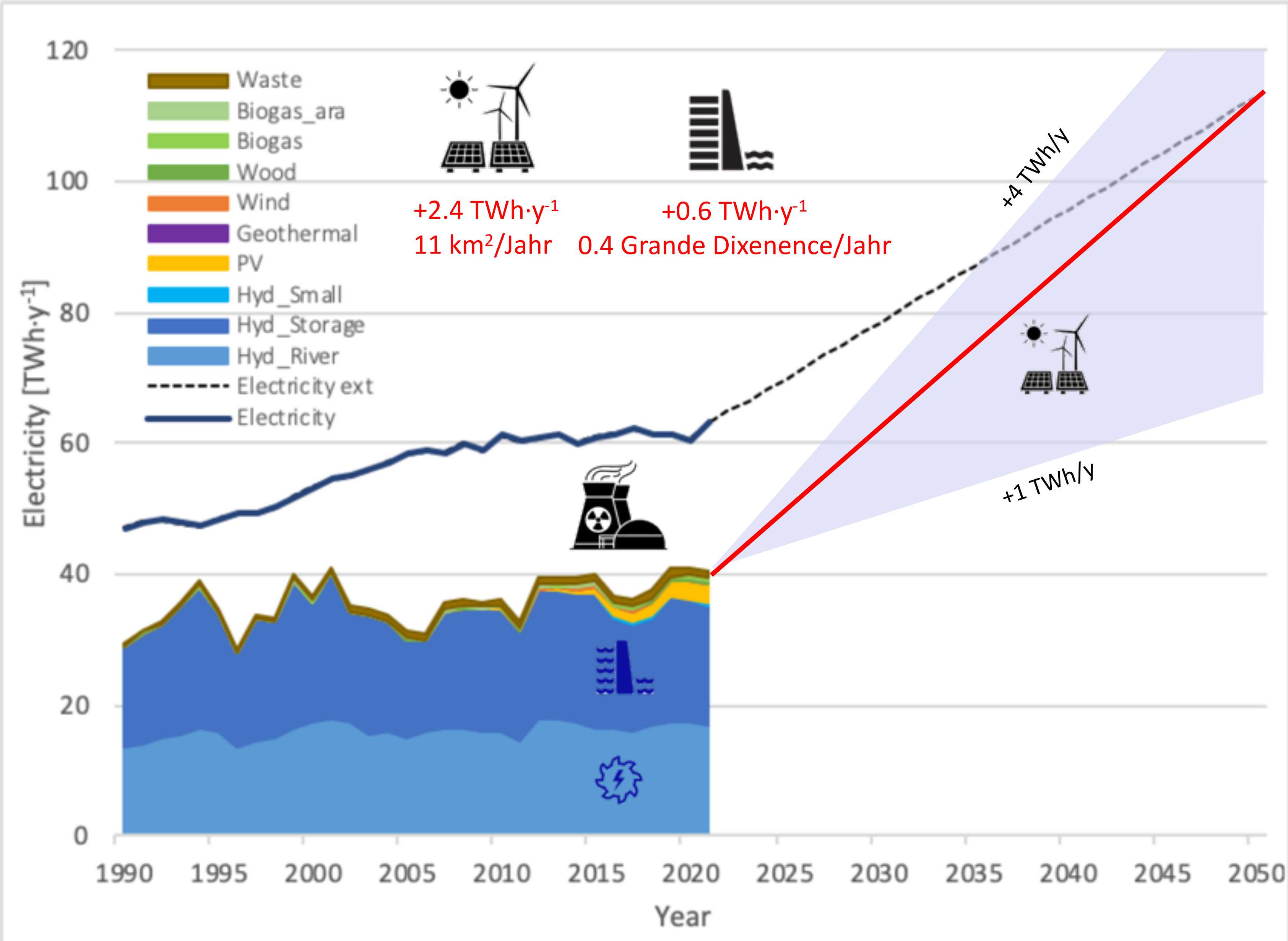
Total: 156 TWh·y^{-1}





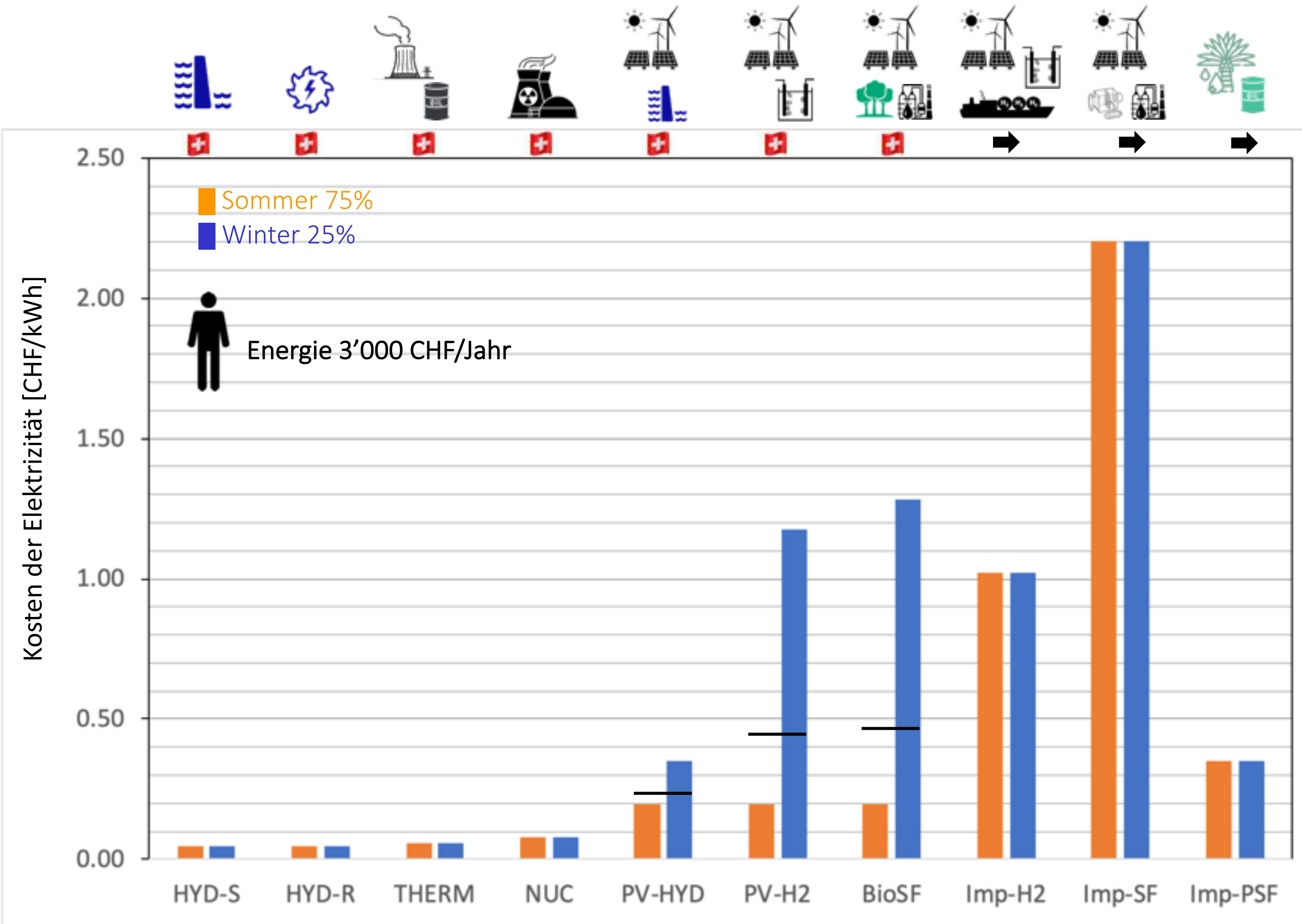


Erneuerbare Energie Entwicklung

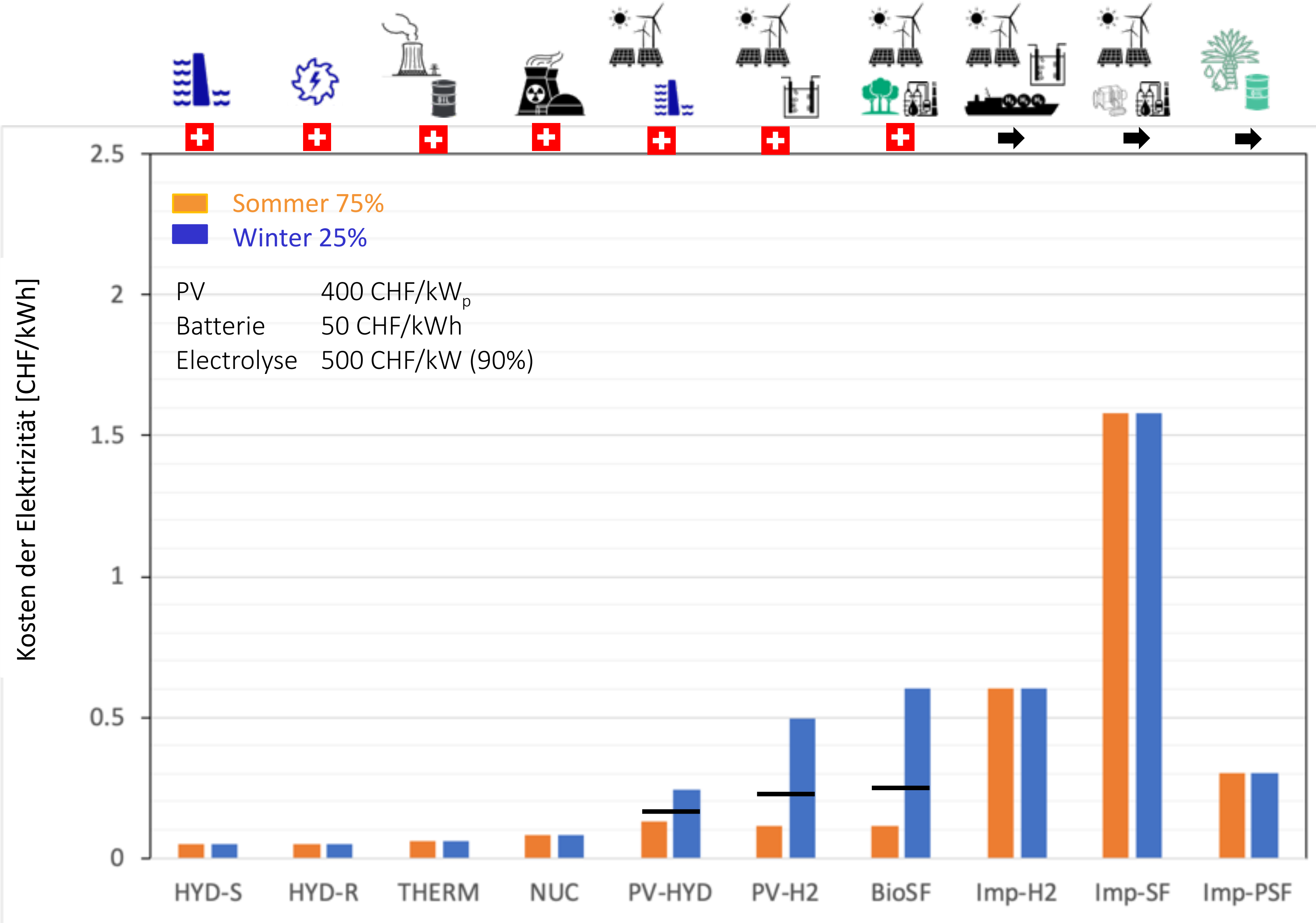


CO$_2$ neutrale Schweiz

Gestehungskosten der Elektrizität (2023)



Gestehungskosten der Elektrizität (Zukunft)



Aufwand der erneuerbaren Energie Lösungen

	2023	Gesetz		H_2	
Kosten [CHF·y^{-1}]	3’000	2’764	3’402	4’402	4’281
CAPEX [BCHF]	0	48-72	228	Speicher 426	384
Area PV [km^2]	6	150	468	672	492
Area Bio [km^2]		(6’200)	(6’200)	(6’200)	29’400 (6’200)

(....) Ausland	H_2 →	→	→
Kosten [CHF·y^{-1}]	9’079 Kosten	15’445 Kosten	4’623
CAPEX [BCHF]	42 (720)	30 (702)	24 (102)
Area PV [km^2]	150 (720)	150 (780)	150 (36)
Area Bio [km^2]	0 (6’200)	0 (6’200 + CO_2 13.8 Mt·y^{-1})	(43’400)

Aufwand der erneuerbaren Energie Lösungen

	2019	Gesetz		H_2	
Kosten [$CHF \cdot y^{-1}$]	3'000	2'764	3'402	4'402	4'281
CAPEX [BCHF]	0	48-72	228	426 Speicher	384
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Area Bio [km^2]		(6'200)	(6'200)	(6'200)	29'400 (6'200)

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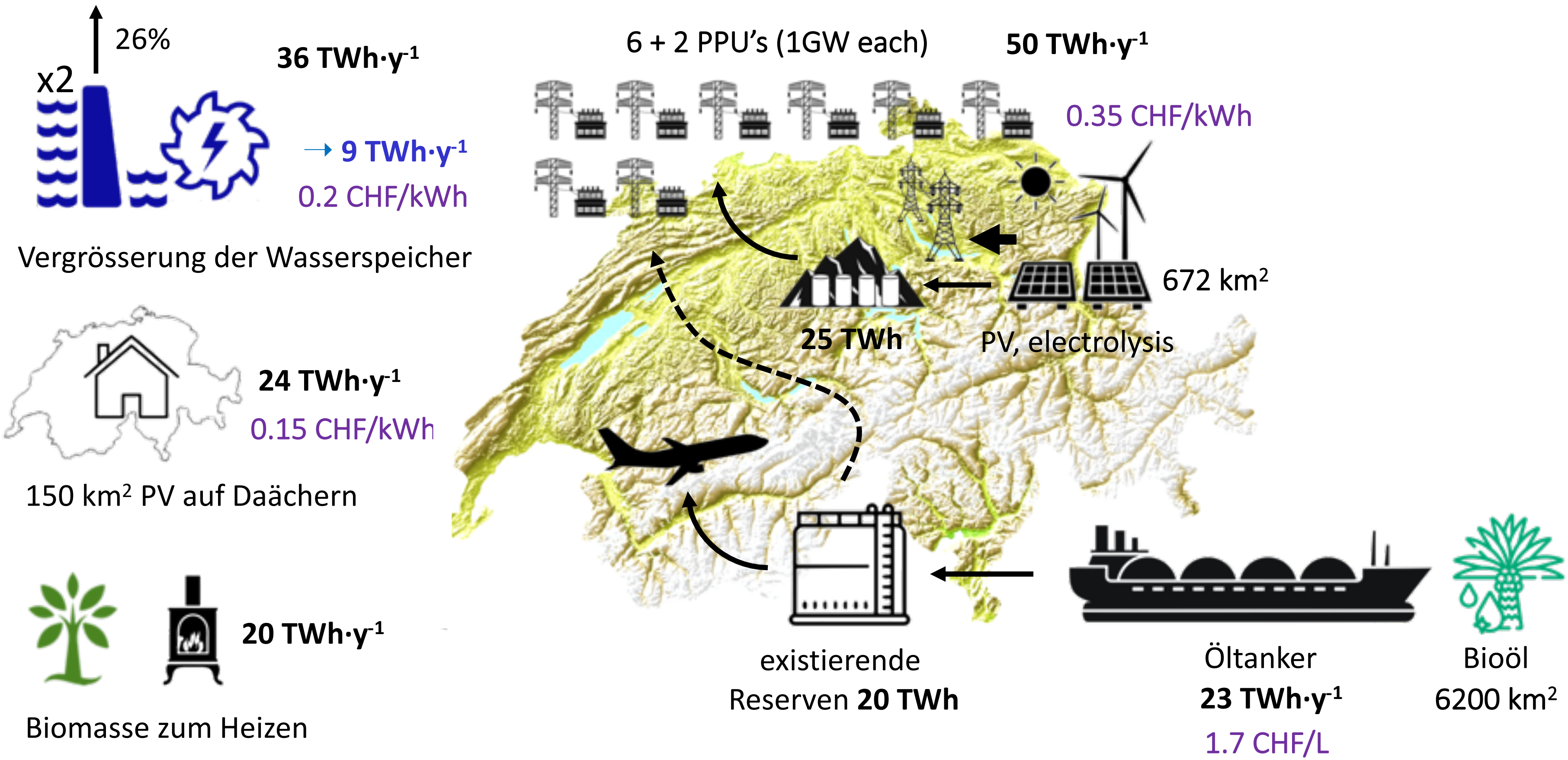
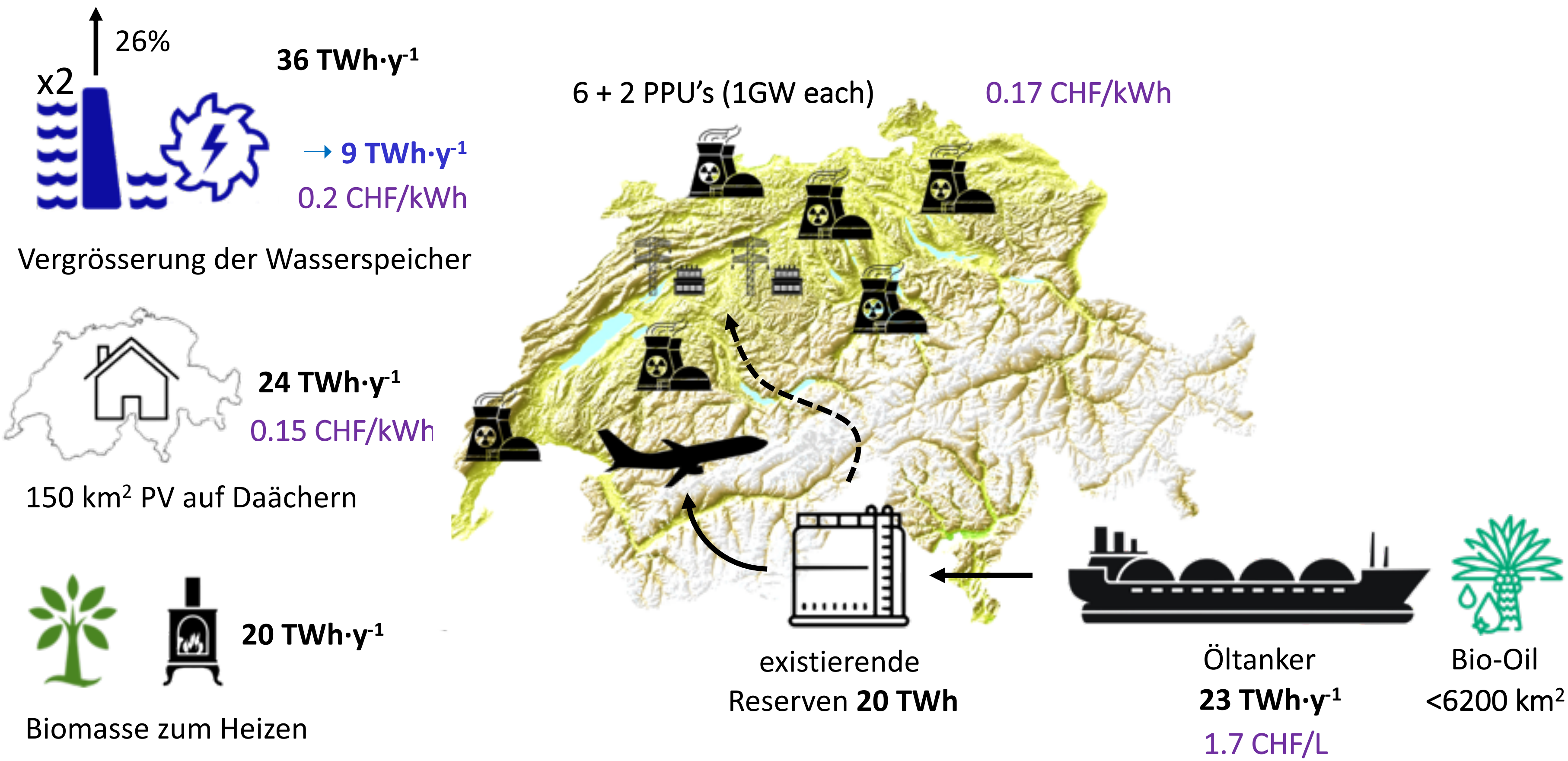
Erneuerbare Energie Lösung (Beispiel)



Senken des Energieverbrauchs durch Wärmenutzung, Wärmespeicher, Isolation

Energie-Committee zur Planung der zukünftigen Energieversorgung

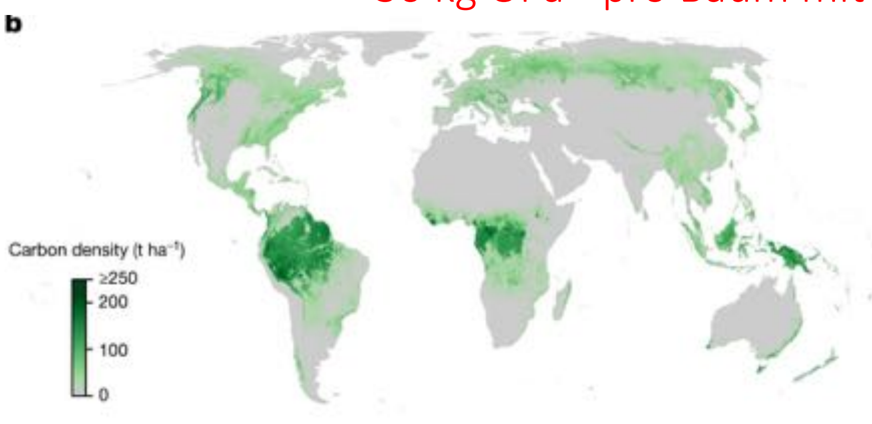
Erneuerbare Energie Lösung (Beispiel)

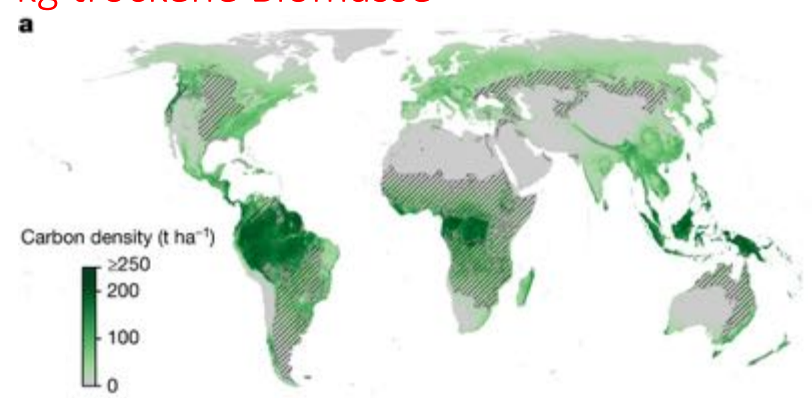


CO_2 Senken und Palmöl Produktion

Derzeit liegt die globale Kohlenstoffspeicherung in Wäldern deutlich unter dem natürlichen Potenzial, mit einem Gesamtdefizit von 226 GtC (Modellbereich = 151 – 363 GtC) in Gebieten mit geringem menschlichen Fussabdruck. [1] Bei 142 verfügbaren Ölpalmenstämmen (OPT) pro Hektar Plantagenfläche und einer neu bepflanzten Fläche von 100.550 Hektar im Jahr 2017 belief sich das geschätzte Trockengewicht der erzeugten OPT (74.5 t ha^{-1}) auf insgesamt 7.5 Mio. t [2]. Es werden 4.0 $t \cdot ha^{-1} \cdot y^{-1}$ Palmöl produziert und die Ölpflanzen werden alle 20 Jahre neu gepflanzt.

30 kg $Öl \cdot a^{-1}$ pro Baum mit 524 kg trockene Biomasse





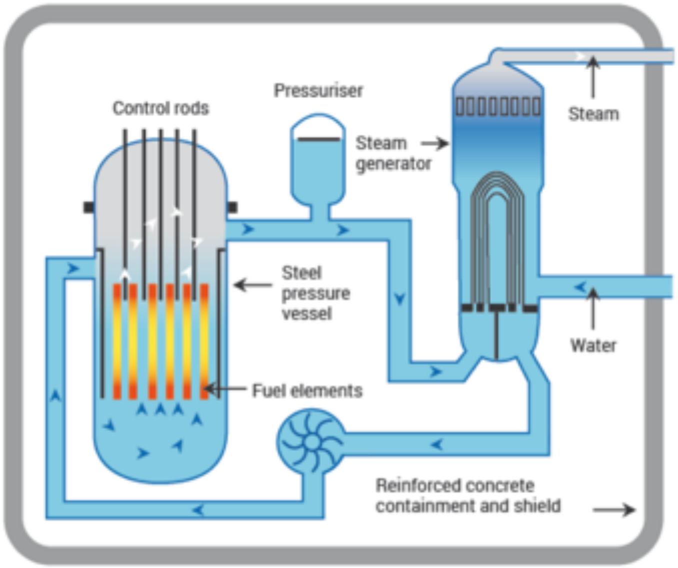
226 Gt Ölpalmen produzieren 13 Gt $Öl \cdot a^{-1}$ mehr als der Weltenergiebedarf an Öl

Ref.: [1] Mo, L., Zohner, C.M., Reich, P.B. et al. Integrated global assessment of the natural forest carbon potential. Nature (2023). https://doi.org/10.1038/s41586-023-06723-z
[2] Thiruchelvi Pulingam, Manoj Lakshmanan, Jo-Ann Chuah, Arthy Surendran, Idris Zainab-La, Parisa Foroozandeh, Ayaka Uked, Akihiko Kosugid, Kumar Sudesh "Oil palm trunk waste: Environmental impacts and management strategies", Industrial Crops & Products 189 (2022), 115827

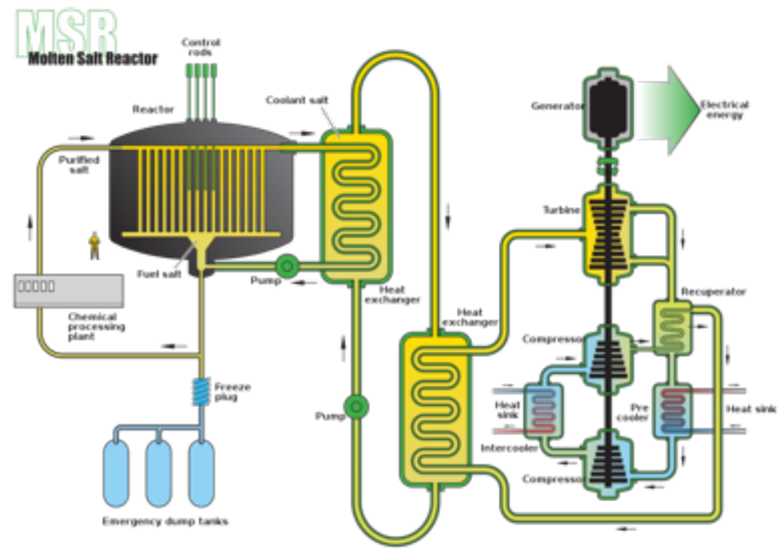
Kernreaktoren

ZUKUNFT

Uran-Spalt-Reaktoren



Thorium-Flüssigsalz-Brutreaktoren



Nachteile:

Begrenzte Uranreserven (6 % für 100 Jahre)
Gefahr des Kernschmelzens
Langlebige Isotope (Pu)
geringer Wirkungsgrad (25%)
begrenzte Wärmenutzung
Endlager von Nuc. Abfall
Kleine modulare Reaktoren (SMR)

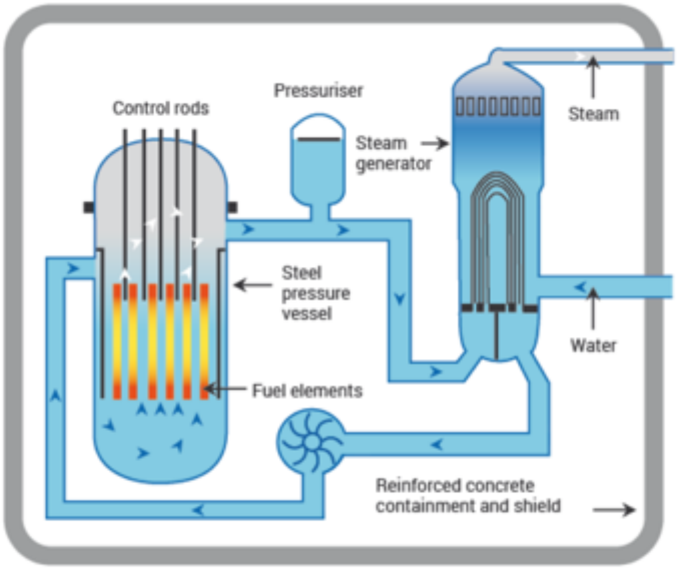
Vorteile:

Große Thoriumreserven (Verwendung von Atommüll, 95 % sind Brennstoff)
Kein Kernschmelzen möglich
Keine langlebigen Isotope
höhere T, höhere Effizienz (>25%)
Nutzung von Wärme zum Heizen
Schmelzsalzreaktor (MSR)

Kernreaktoren

ZUKUNFT

Uran-Spalt-Reaktoren



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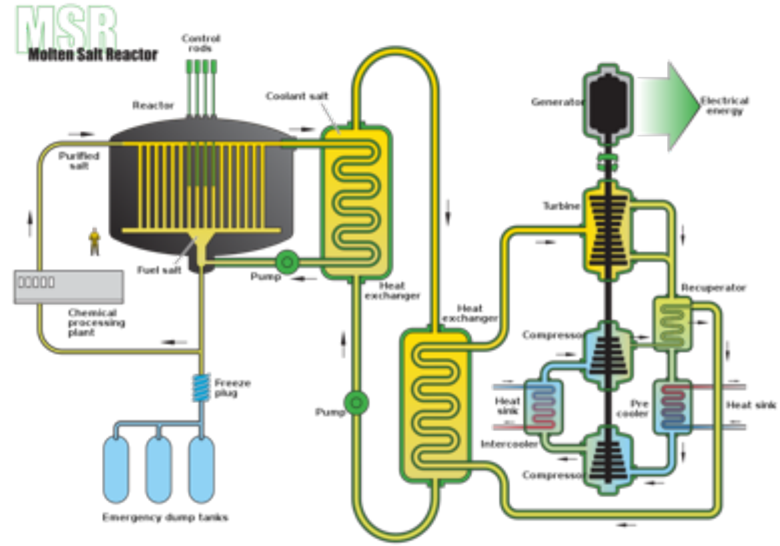
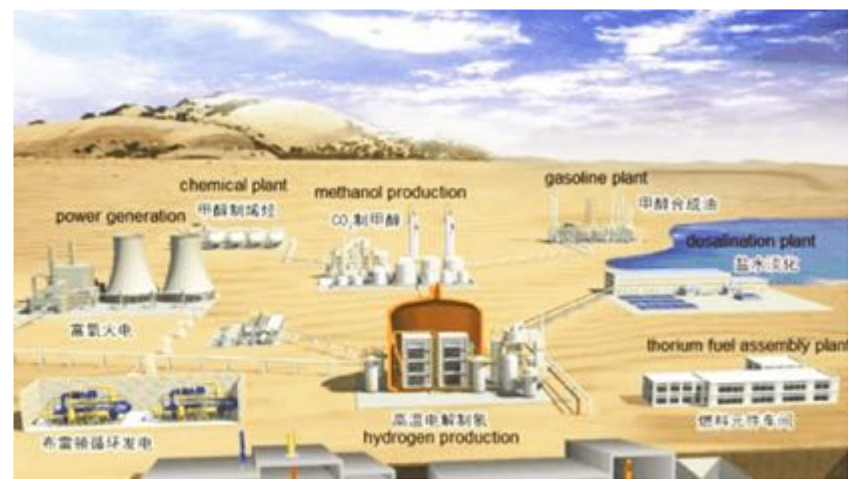
Ref.: https://www.world-nuclear-news.org/Articles/Operating-permit-issued-for-Chinese-molten-salt-re

Thorium-Flüssigsalz-Brutreaktoren

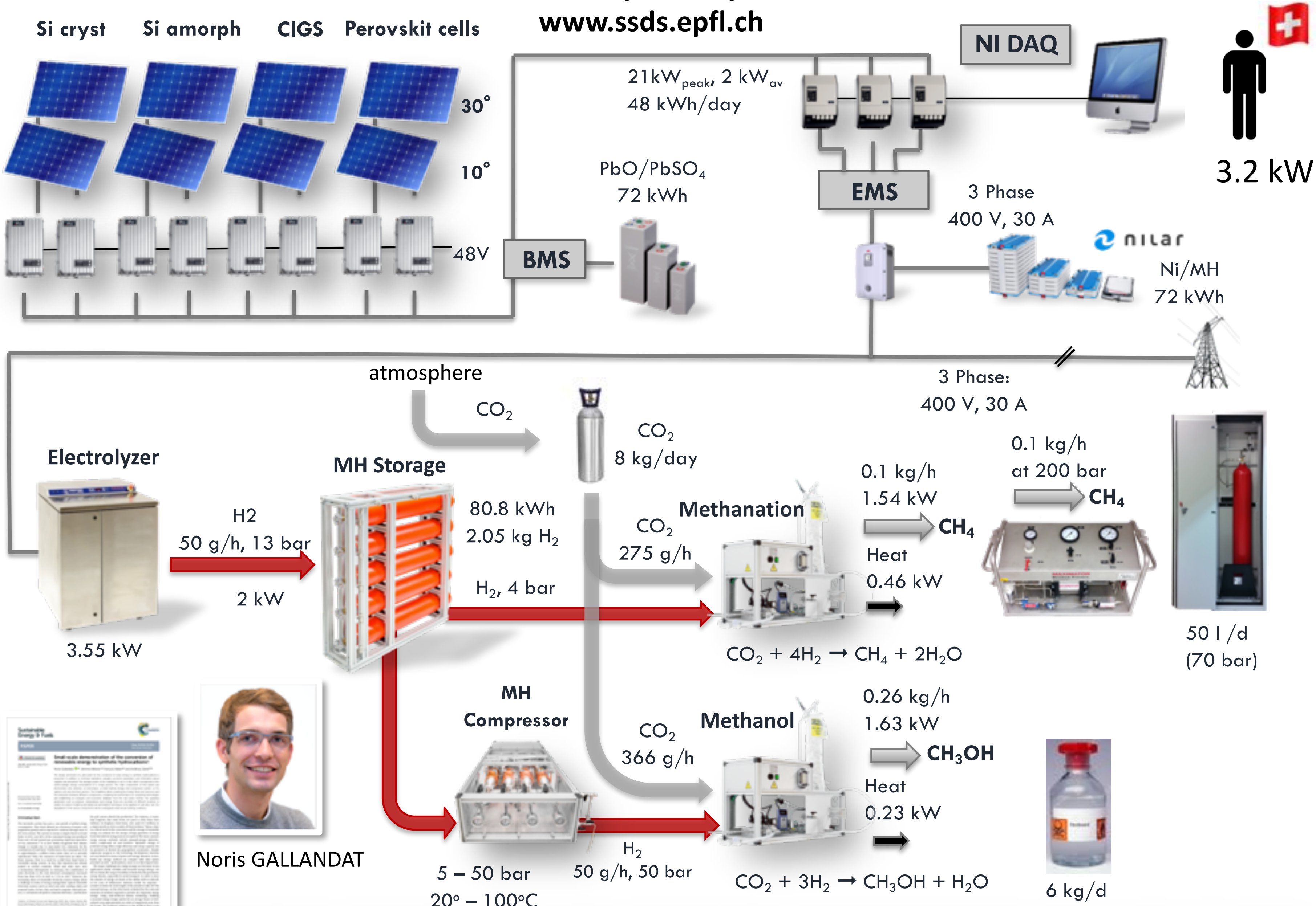




TMSR-LF1 (2 $MW_{therm.}$) construction 2018 - 2023, Wuwei city, Gansu province, China, operated since July 2023

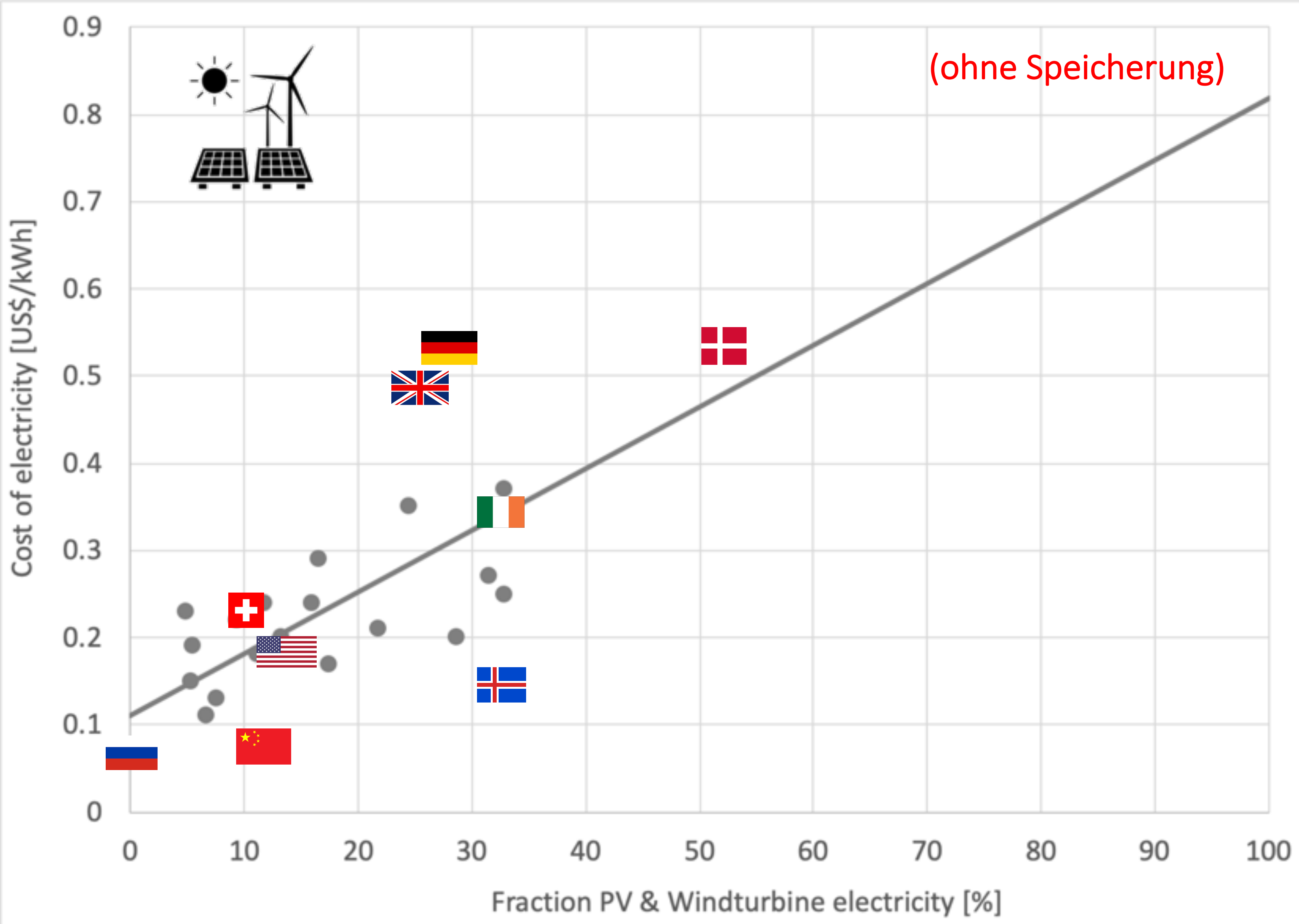
Small Scale Demonstrator Sion (SSDS)

www.ssds.epfl.ch

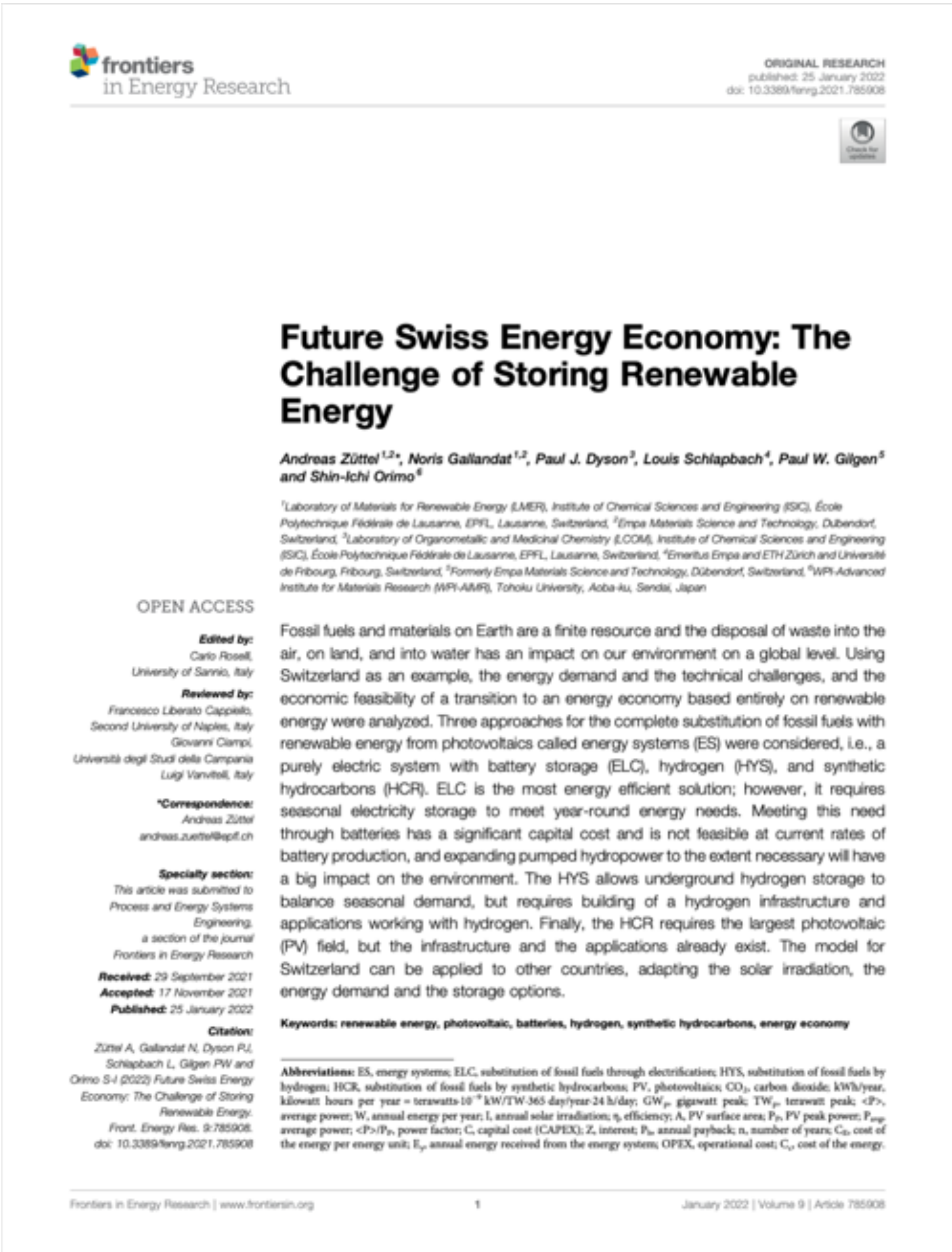


Noris Gallandat, Jérémie Bérard, François Abbet and Andreas Züttel, “Small-scale demonstration of the conversion of renewable energy to synthetic hydrocarbons”, Sustainable Energy & Fuels (2017).DOI: 10.1039/c7se00275k, rsc.li/sustainable-energy

Kosten der Elektrizität aus PV und Windturbinen (2023)



Ref.: https://elements.visualcapitalist.com/mapped-solar-and-wind-power-by-country/



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Future Swiss Energy Economy: The Challenge of Storing Renewable Energy

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Fossil fuels and materials on Earth are a finite resource and the disposal of waste into the air, on land, and into water has an impact on our environment on a global level. Using Switzerland as an example, the energy demand and the technical challenges, and the economic feasibility of a transition to an energy economy based entirely on renewable energy were analyzed. Three approaches for the complete substitution of fossil fuels with renewable energy from photovoltaics called energy systems (ES) were considered, i.e., a purely electric system with battery storage (ELC), hydrogen (HYS), and synthetic hydrocarbons (HCR). ELC is the most energy efficient solution; however, it requires seasonal electricity storage to meet year-round energy needs. Meeting this need through batteries has a significant capital cost and is not feasible at current rates of battery production, and expanding pumped hydropower to the extent necessary will have a big impact on the environment. The HYS allows underground hydrogen storage to balance seasonal demand, but requires building of a hydrogen infrastructure and applications working with hydrogen. Finally, the HCR requires the largest photovoltaic (PV) field, but the infrastructure and the applications already exist. The model for Switzerland can be applied to other countries, adapting the solar irradiation, the energy demand and the storage options.

Keywords: renewable energy, photovoltaic, batteries, hydrogen, synthetic hydrocarbons, energy economy

Abbreviations: ES, energy systems; ELC, substitution of fossil fuels through electrification; HYS, substitution of fossil fuels by hydrogen; HCR, substitution of fossil fuels by synthetic hydrocarbons; PV, photovoltaics; CO_2, carbon dioxide; kWh/year, kilowatt hours per year = terawatts·10^{-9} kW/TW·365 day/year·24 h/day; GW_p, gigawatt peak; TW_p, terawatt peak; <P>, average power; W, annual energy per year; I, annual solar irradiation; η, efficiency; A, PV surface area; P_P, PV peak power; P_{avg}, average power; <P>/P_P, power factor; C, capital cost (CAPEX); Z, interest; P_b, annual payback; n, number of years; C_E, cost of the energy per energy unit; E_y, annual energy received from the energy system; OPEX, operational cost; C_c, cost of the energy.

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