CO$_2$ Neutral Energy Security for Switzerland

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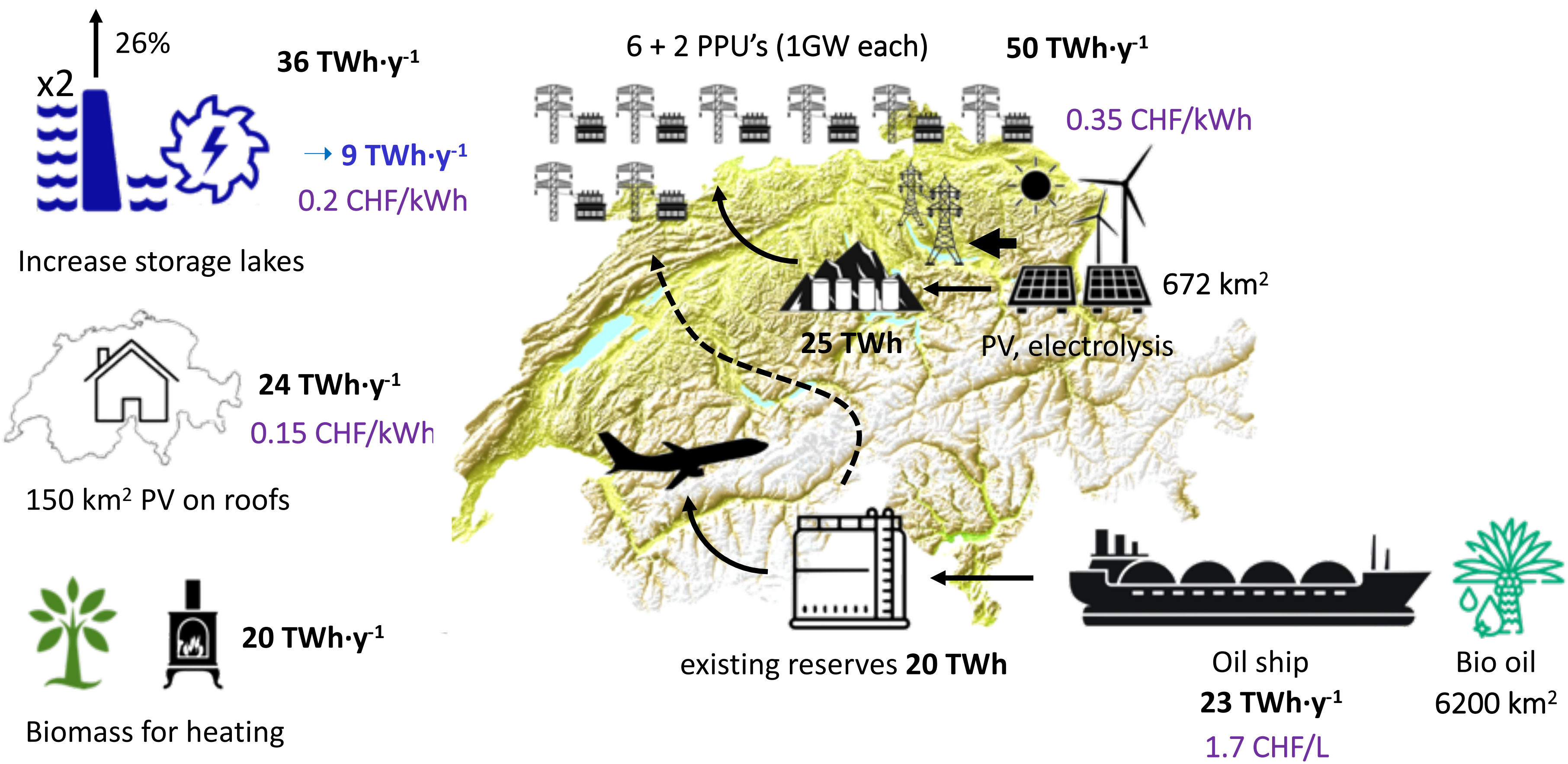
ABSTRACT

An analysis of the technical oportunities and economic consequences of the transition from fossil fuels to renewable energy in Switzerland is presented. The technically realized efficiencies showed that complete electrification leads to the most efficient and cheapest energy system. The electricity demand is expected to almost double, and the overall energy cost will increase by 20% compared to 2019. However, the technical challenges of seasonal electricity storage, without any reserves and redundancy, amounts to 20 TWh.

Future nuclear fission technologies, e.g. molten salt Thorium breading reactor - currently still in a experimental stage – might become the most economical and least environmental impact solution for CO_2 neutral energy production for Switzerland The opportunities for a massive increase of hydroelectric production are limited, already shifting the use of water (9 TWh) from summer to winter is a great challenge. PV and hydrogen production in Switzerland have the advantage to provide approximately 75% of the electricity without seasonal storage leading to significantly lower electricity cost than imported hydrogen or synthetic hydrocarbons. The most economical solution for aviation and reserves is imported bio-oil converted to synthetic Kerosene, for which large storages already exist.

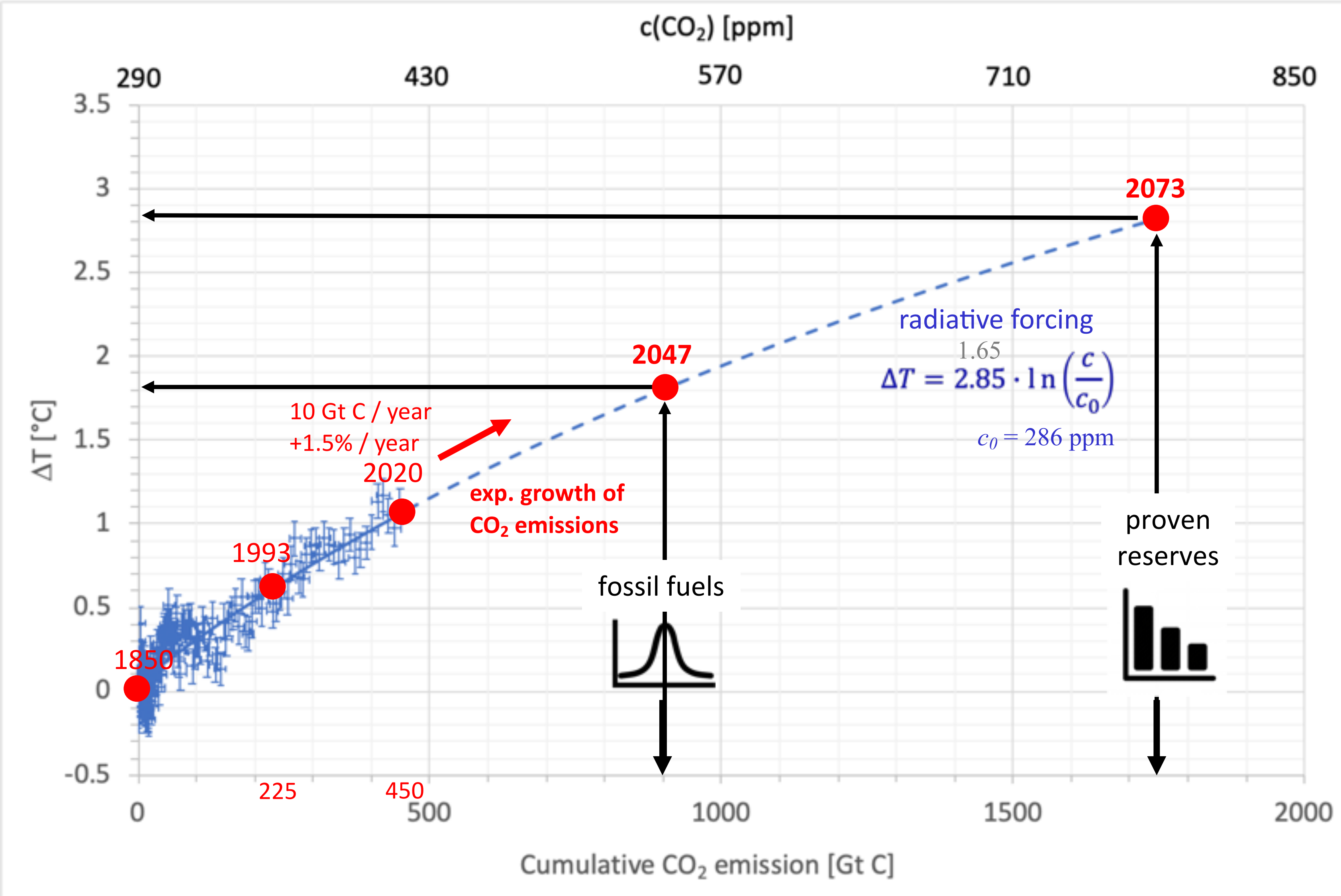
accepted by "Frontiers in Energy Research: Process and Energy Systems Engineering" (2024)

Renewable energy solutions (example)



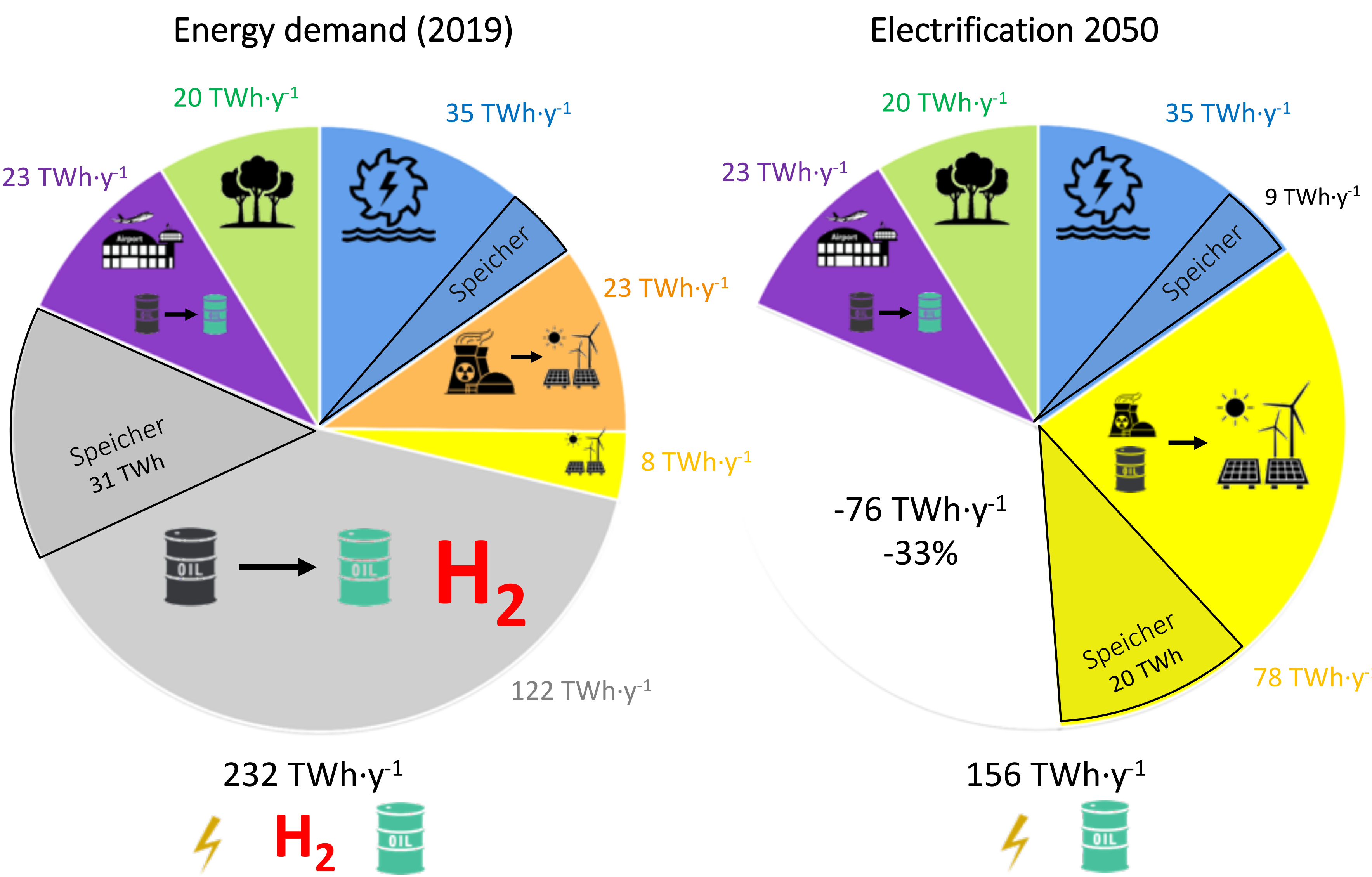
lower energy demand by heat use, heat storage, Insulation

Global Warming vs. Cumulative CO_2 Emissions



Ref.: http://www.globalwarmingequation.info/global%20warming%20eqn.pdf and Ollila, A. (2014), "The potency of carbon dioxide (CO2) as a greenhouse gas", Development in Earth Science, Vol. 2, pp. 20-30, available at: www.seipub.org/des/paperInfo.aspx?ID=17162

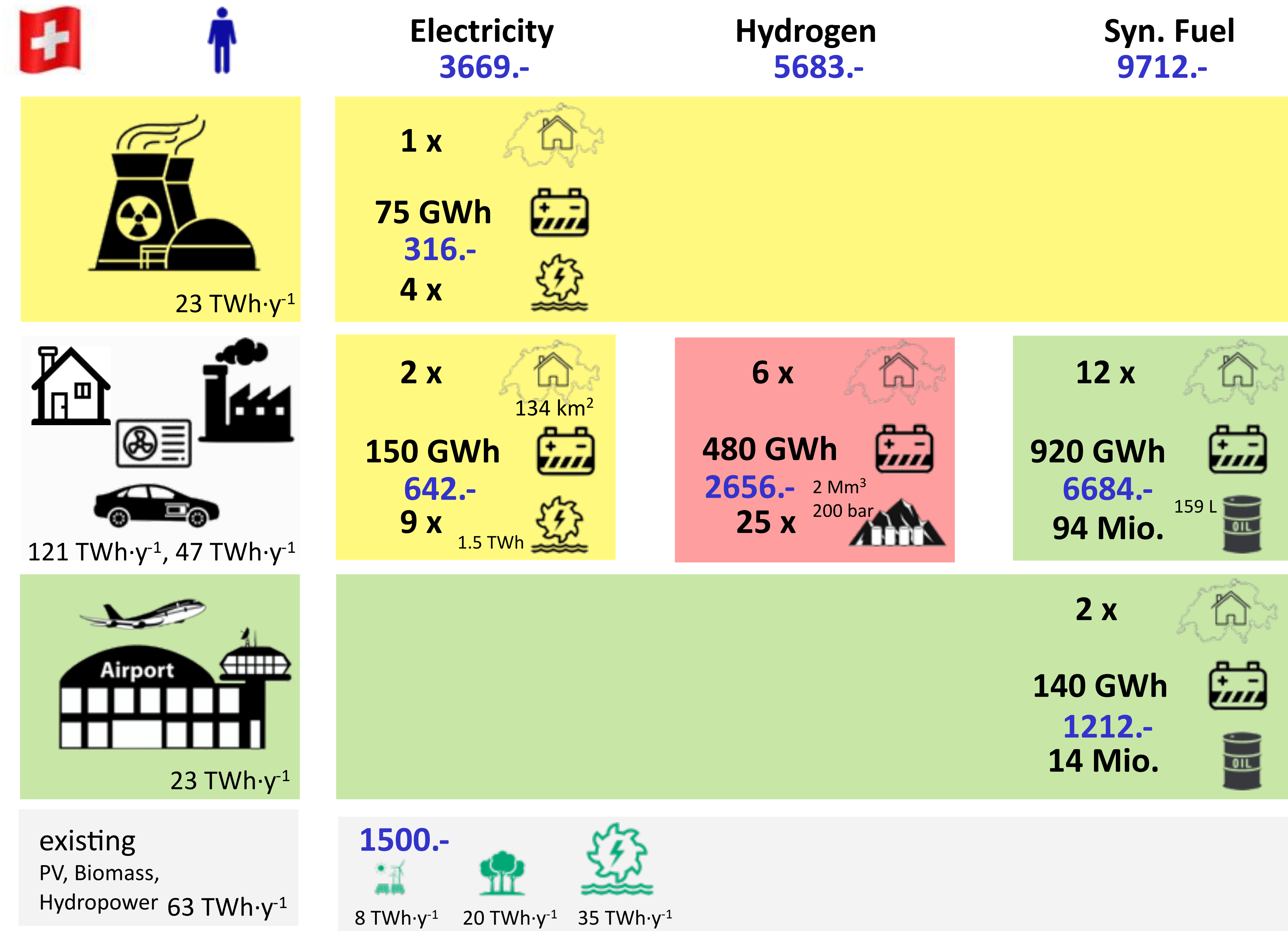
Energy demand by source and electrification



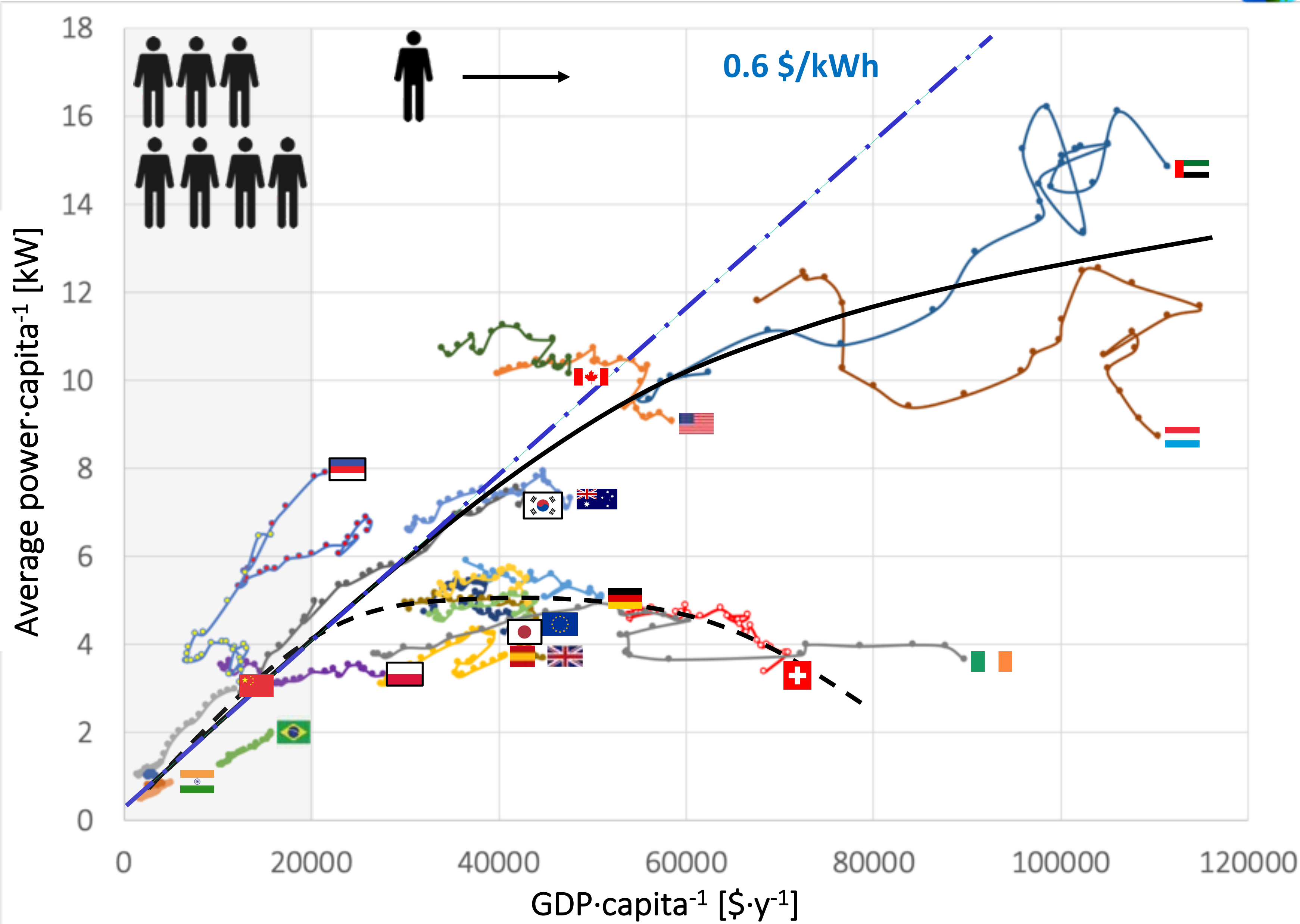
Ref.: SCHWEIZERISCHE GESAMTENERGIE STATISTIK (2019) Art.-Nr. 805.006.19 / 08.20 / 1200 / 860467013, Federal Office of Energy, Switzerland, https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/gesamtenergiestatistik.exturl.html/

Renewable Energy Systems: Summary

CO_2 Neutral Energy Security for Switzerland

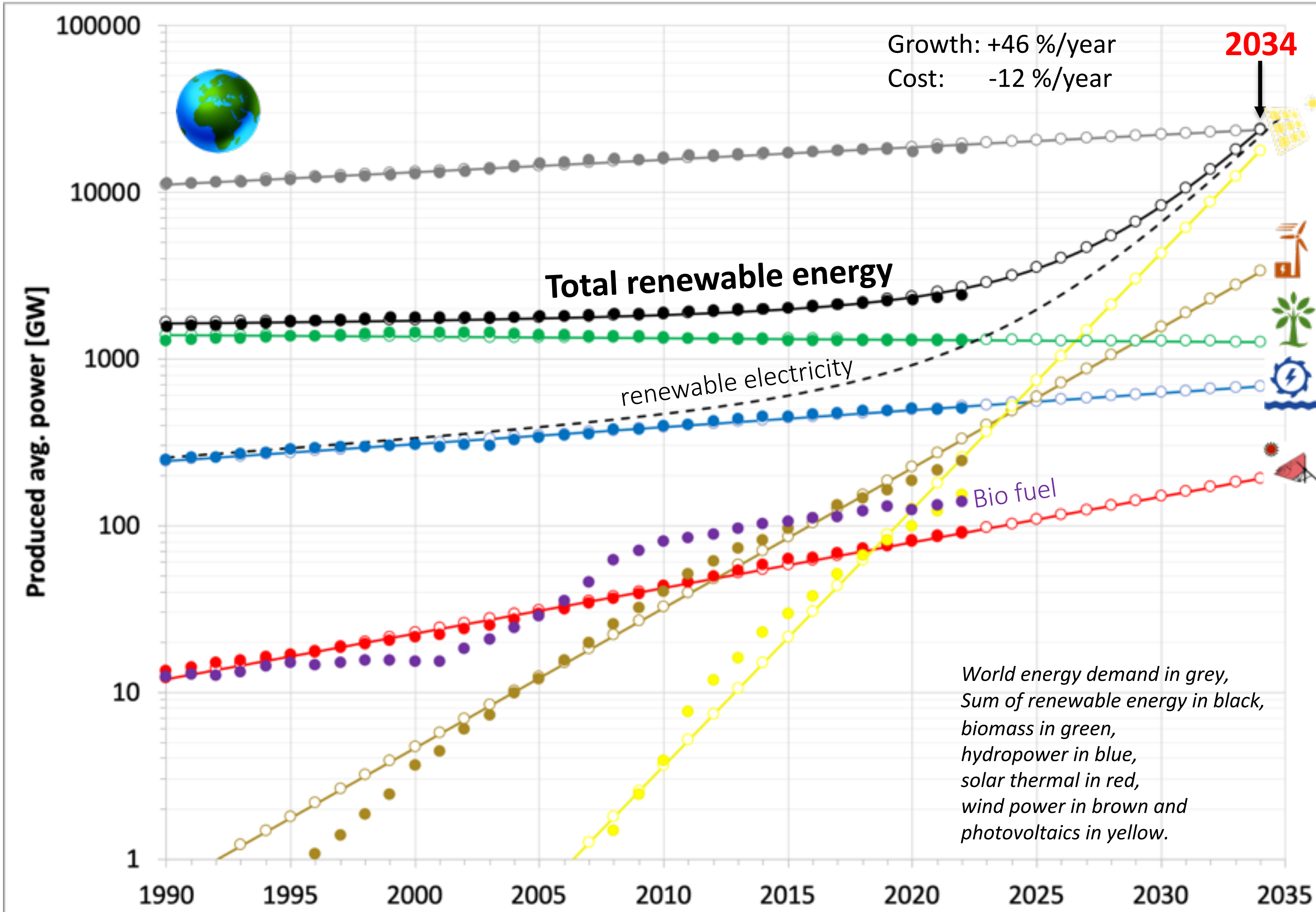


Energy and economy



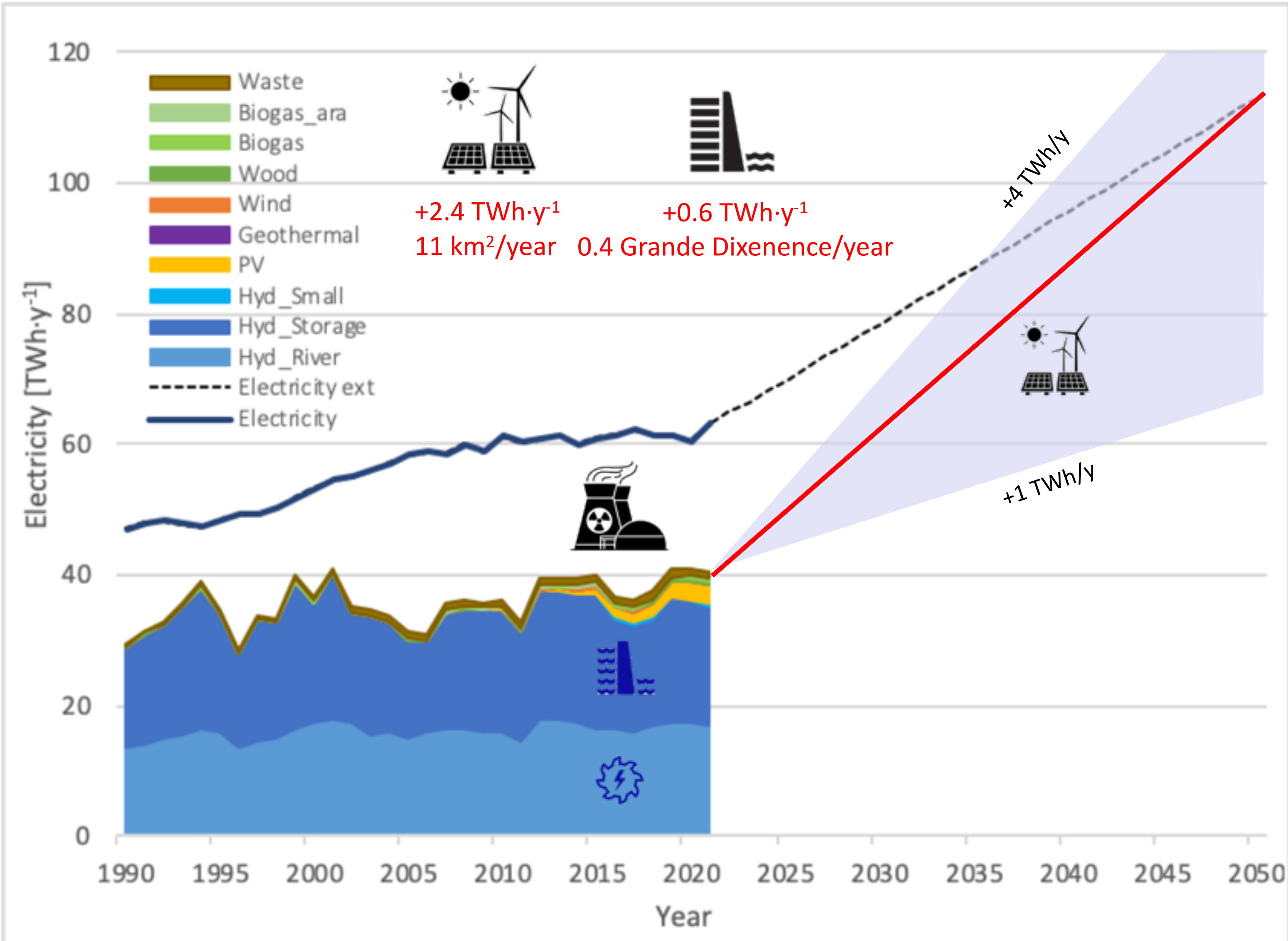
Ref.: https://ourworldindata.org/grapher/energy-use-per-capita-vs-gdp-per-capita

Global renewable energy production

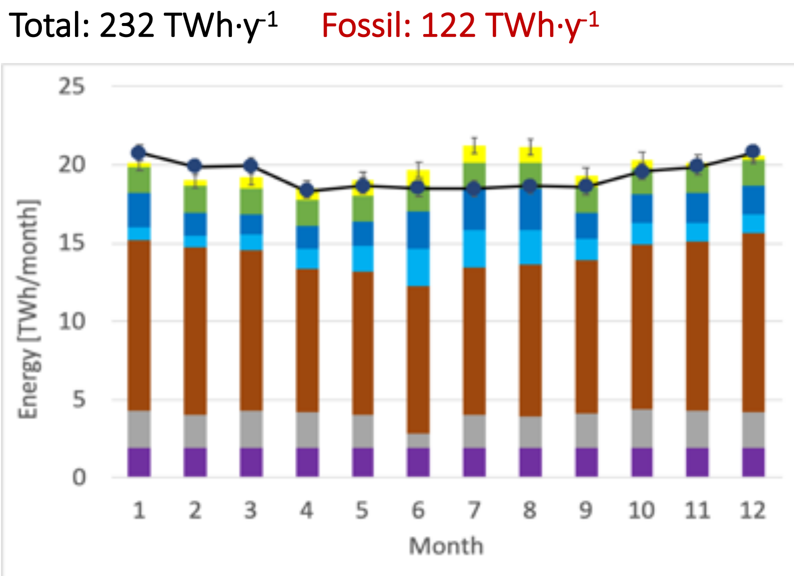


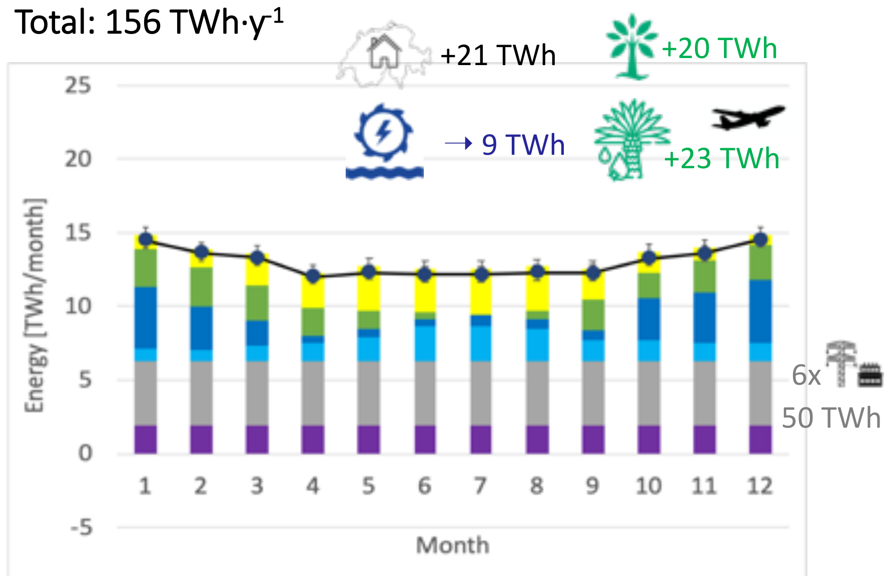
Ref.: https://ourworldindata.org/energy

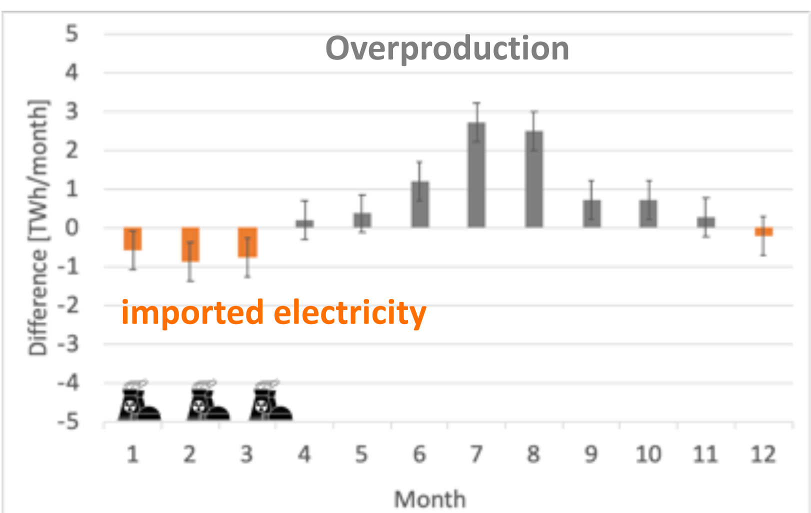
Renewable energy development

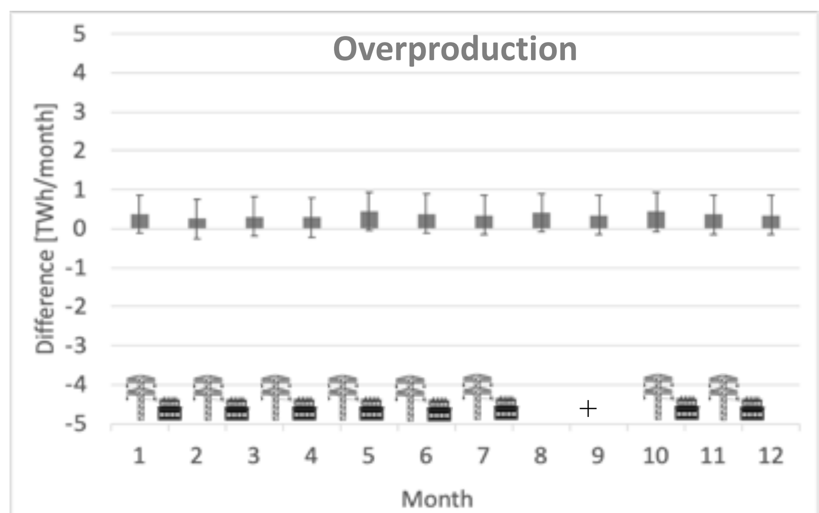


Substitution of fossil with renewable energy

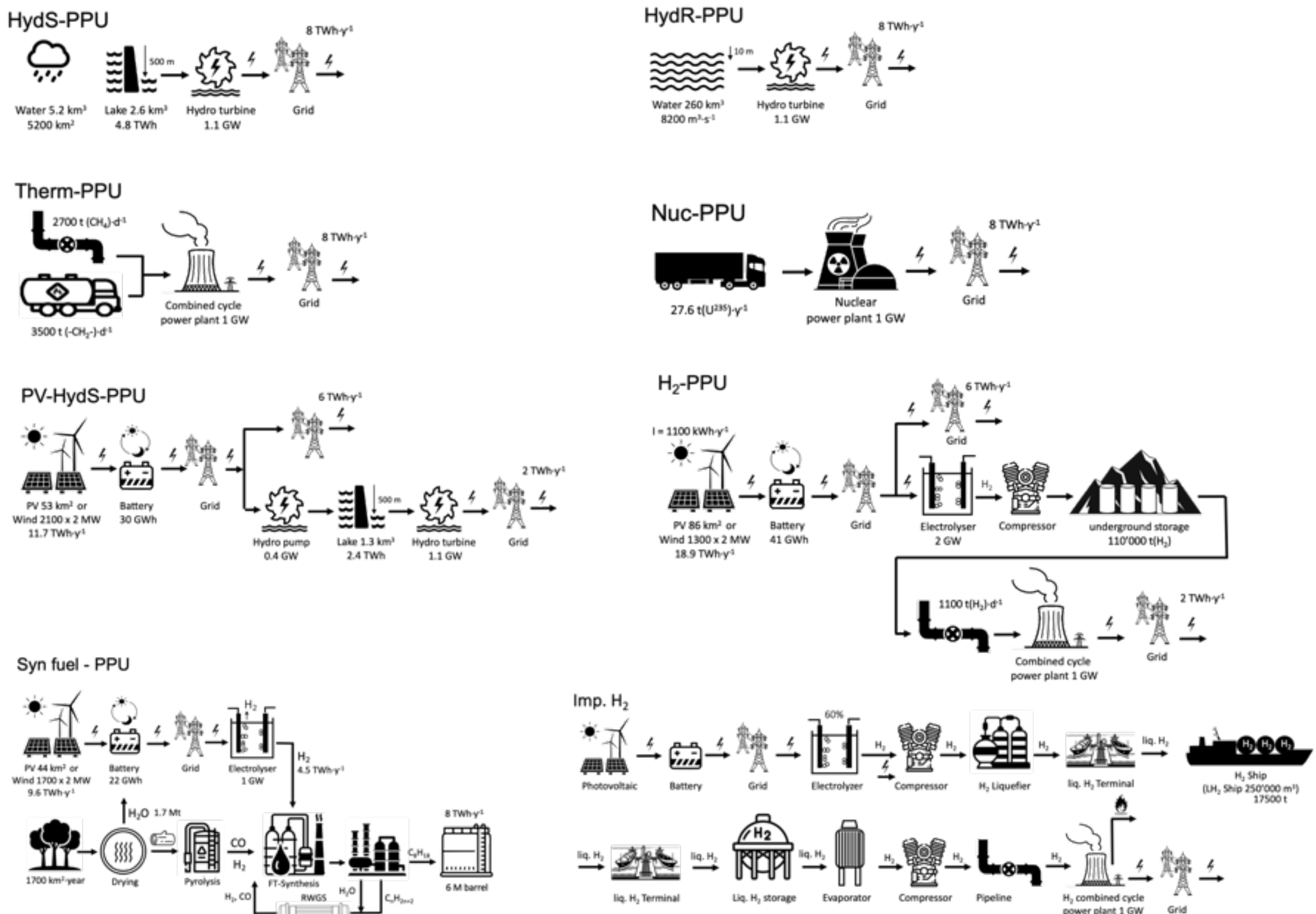




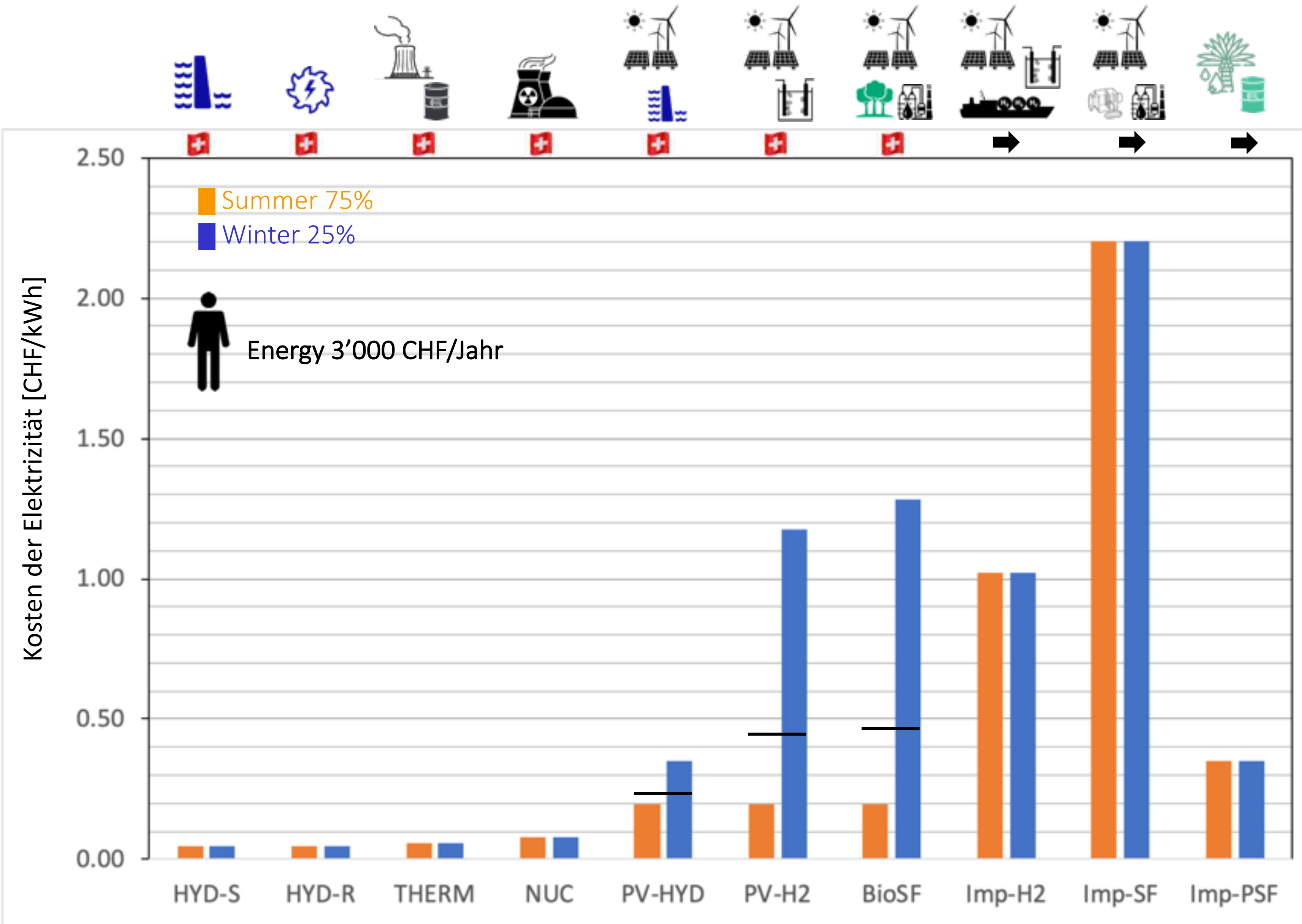




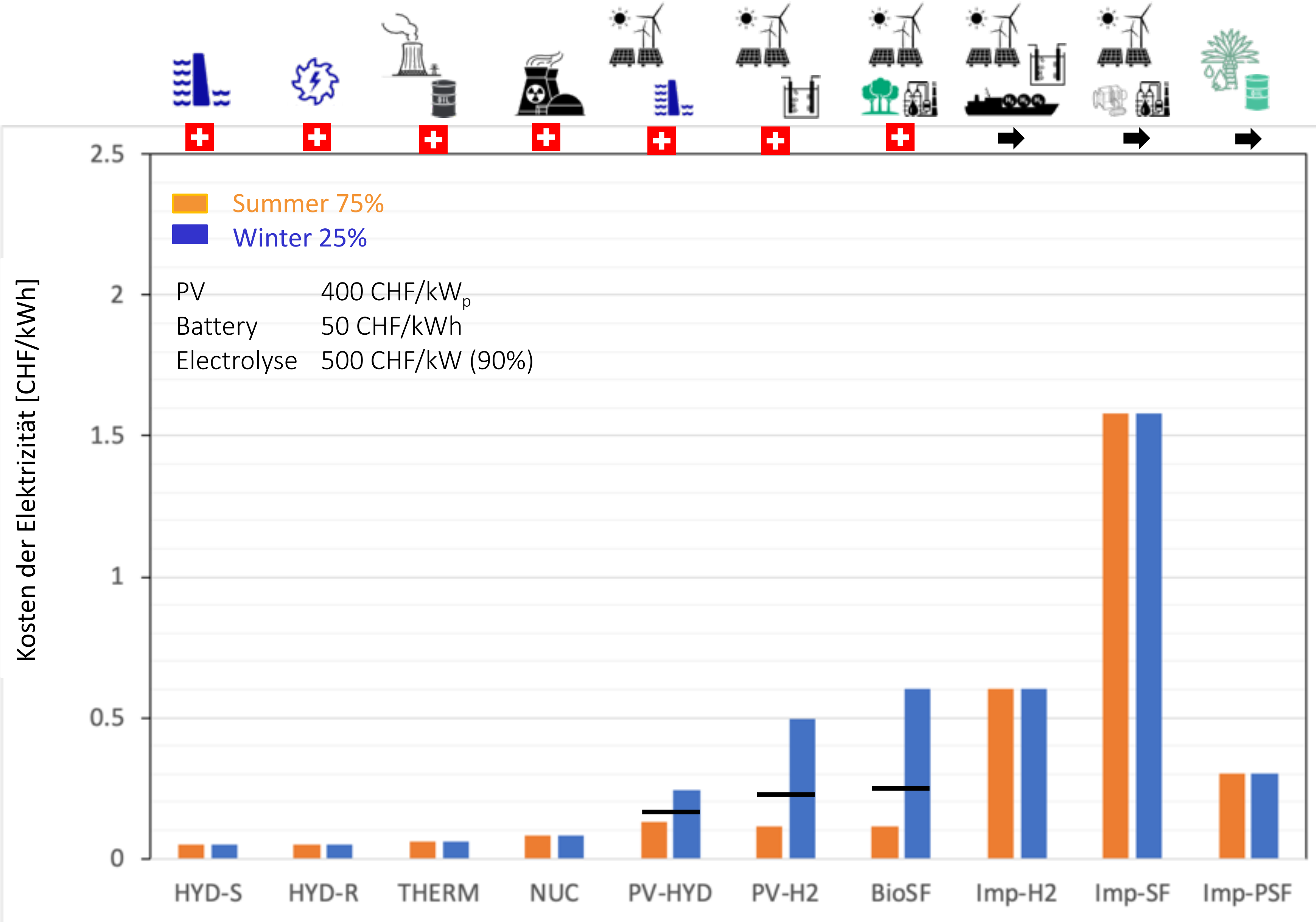
Power plant units



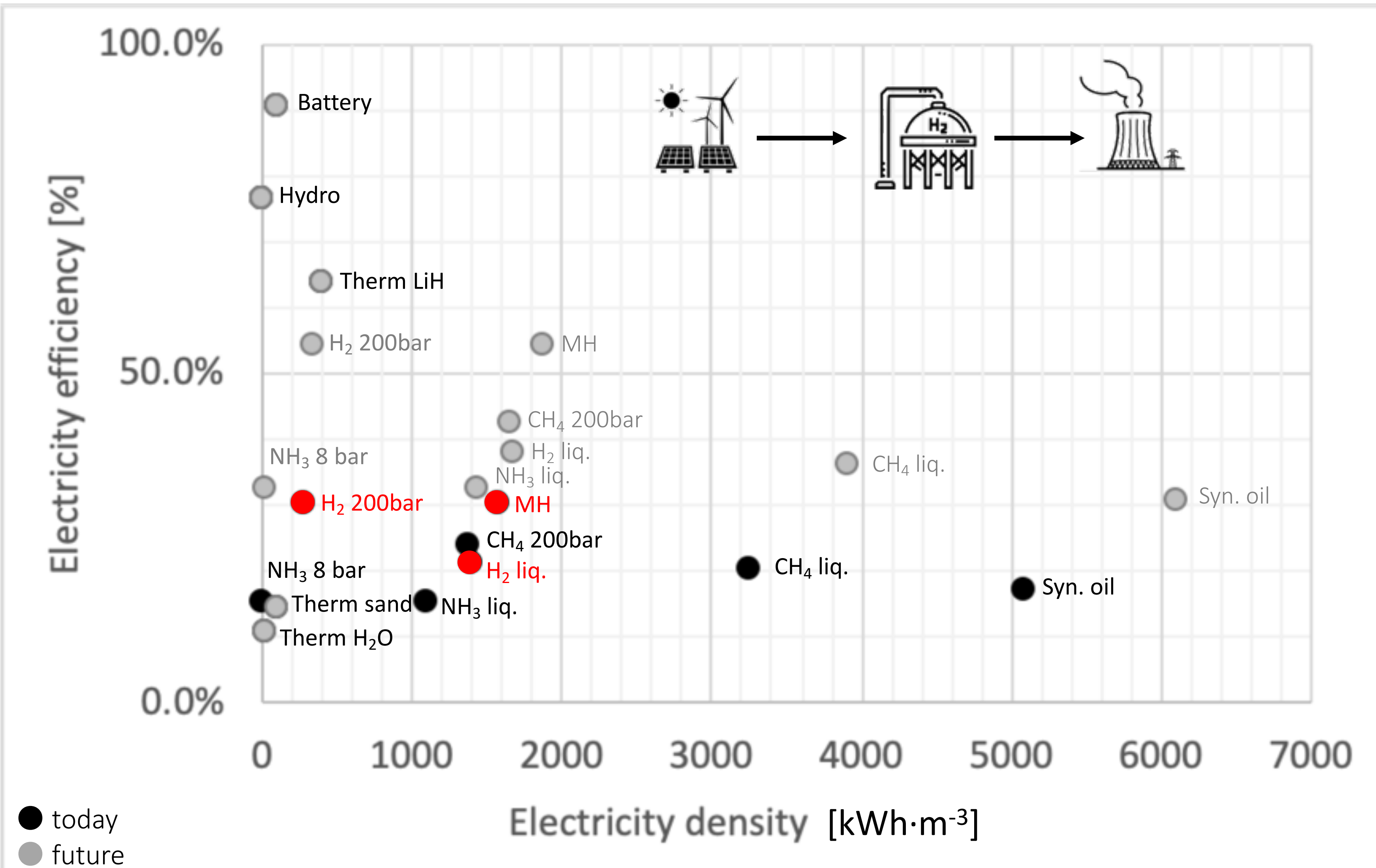
Cost of electricity (2023)



Cost of electricity (future)



Efficiency and storage density of renewable electricity



Renewable energy power plant units

	2023	Law		H_2	
Cost [CHF·y^{-1}]	3’000	2’764	3’402	4’402	4’281
CAPEX [BCHF]	0	48-72	228	Storage 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)

(….) foreign c.	H_2 →	→	→
cost [CHF·y^{-1}]	9’079 Cost	15’445 Cost	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)

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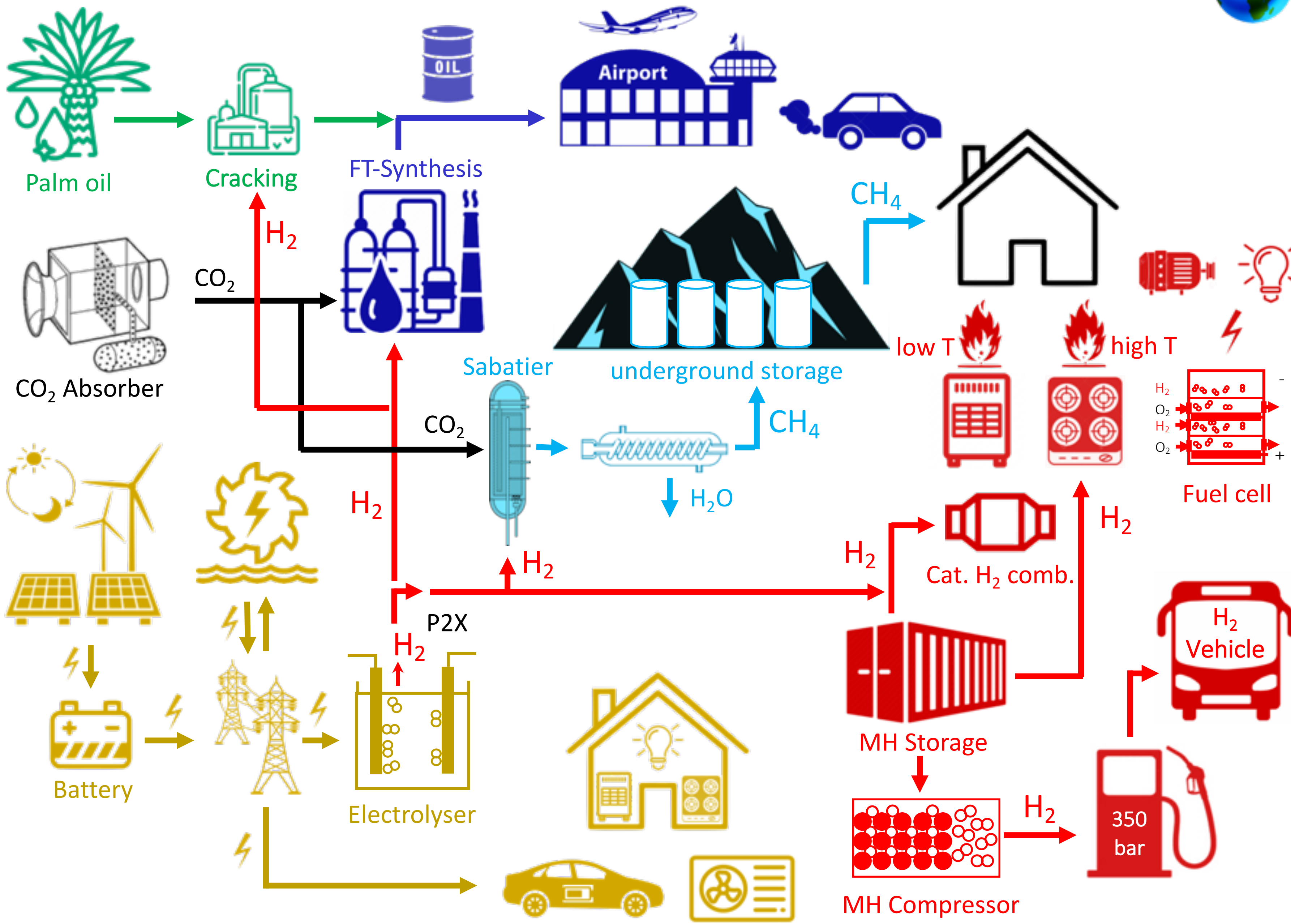
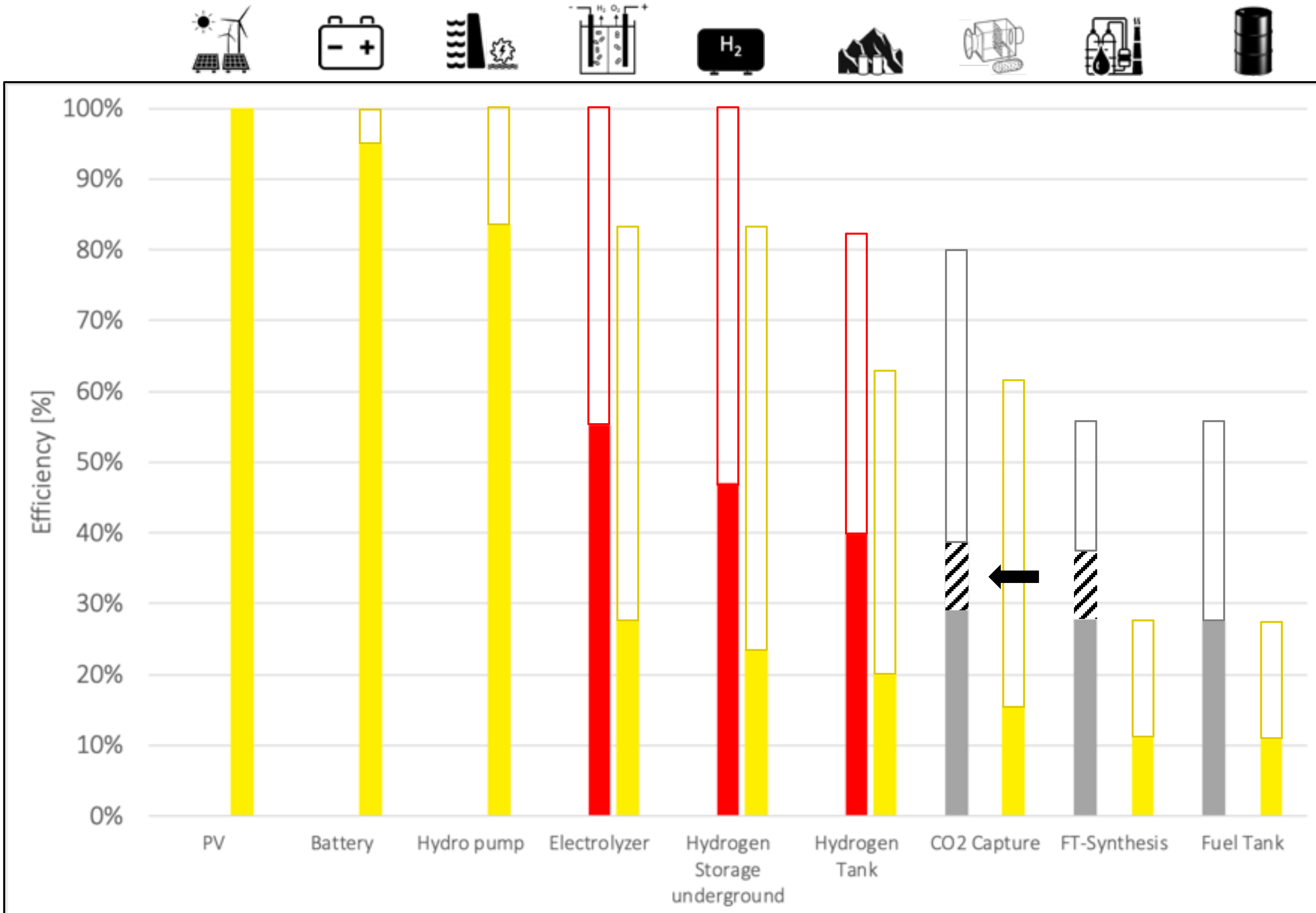
Renewable energy system

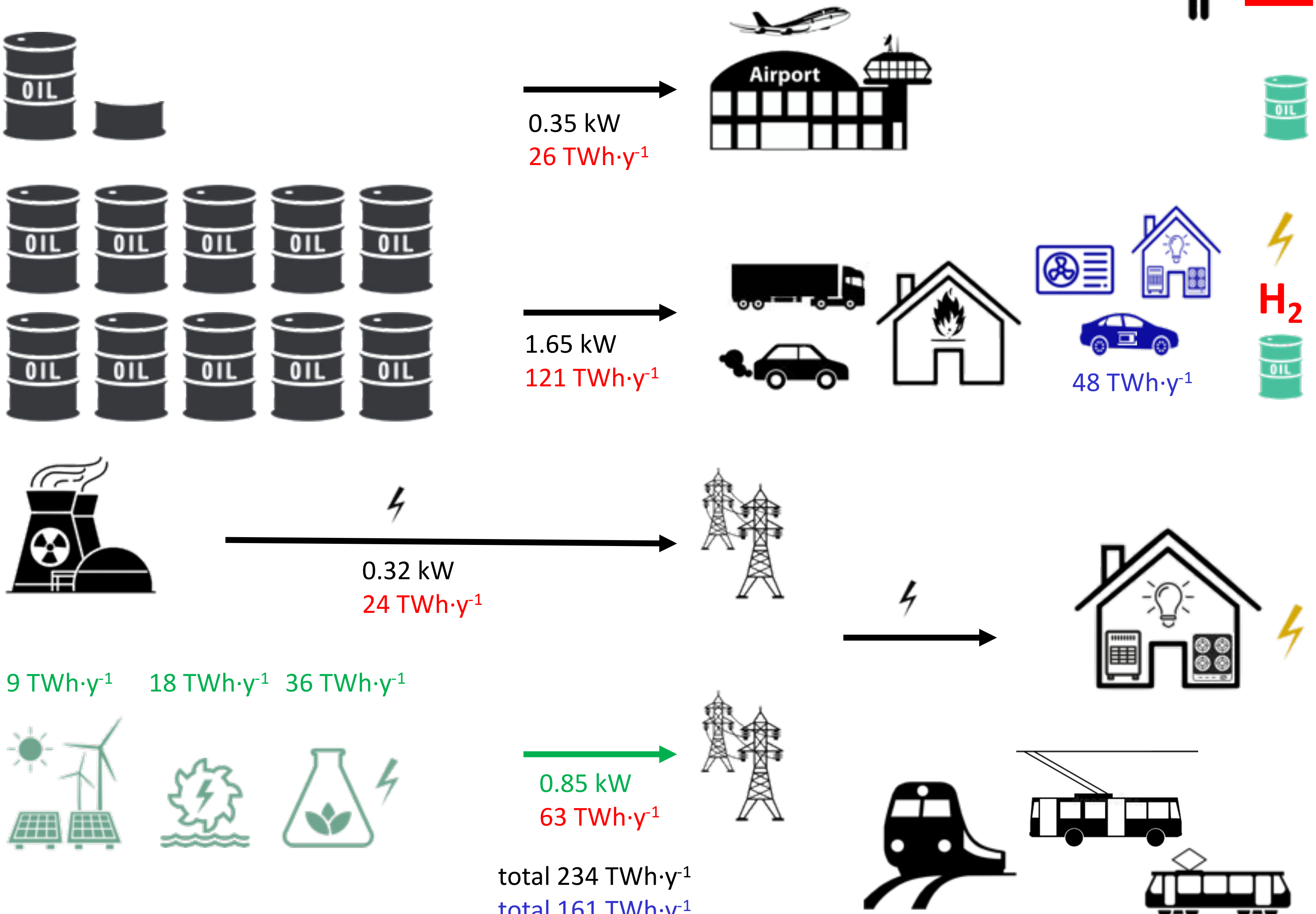


Efficiency of energy conversion

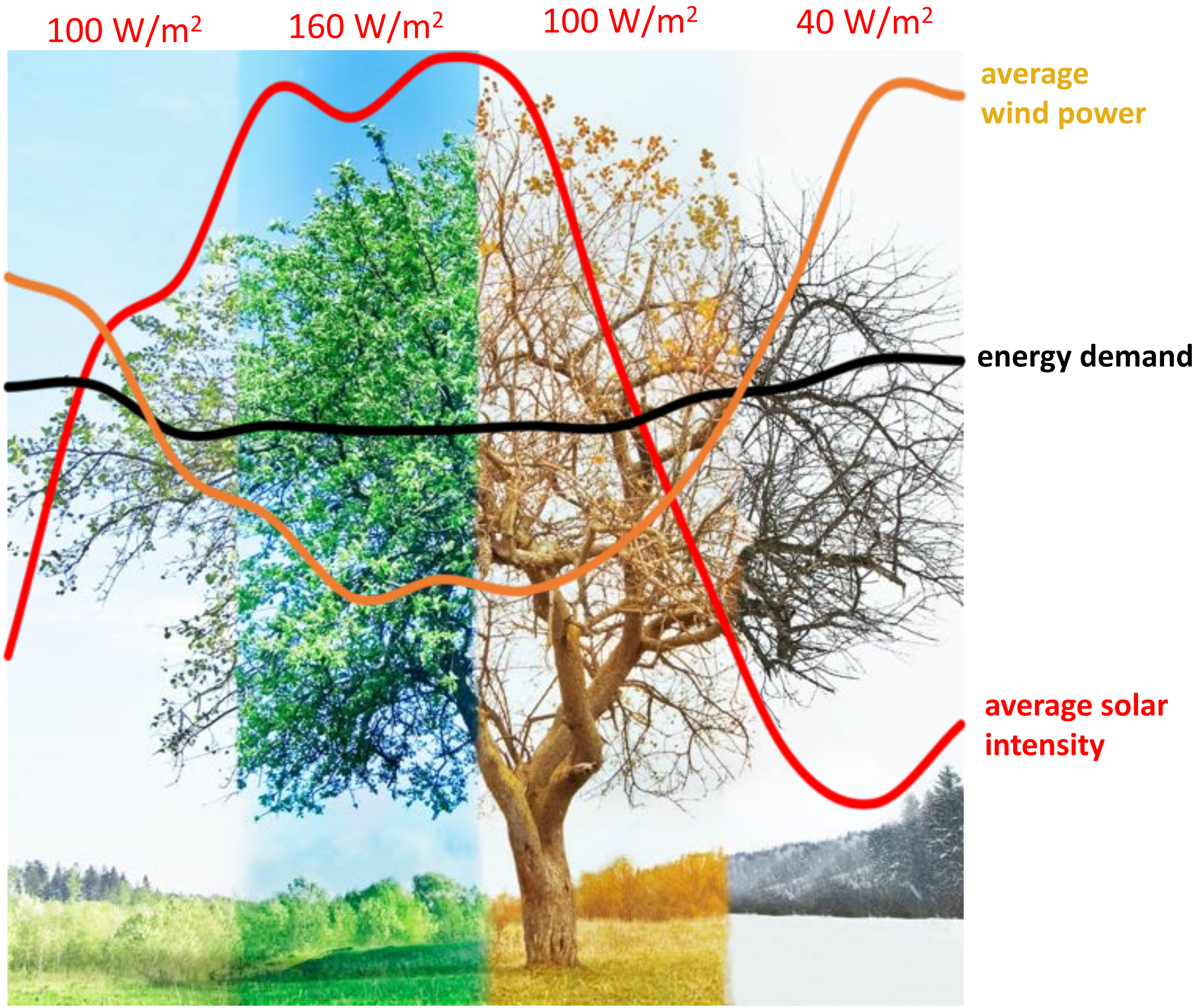
Power to X (P2X)



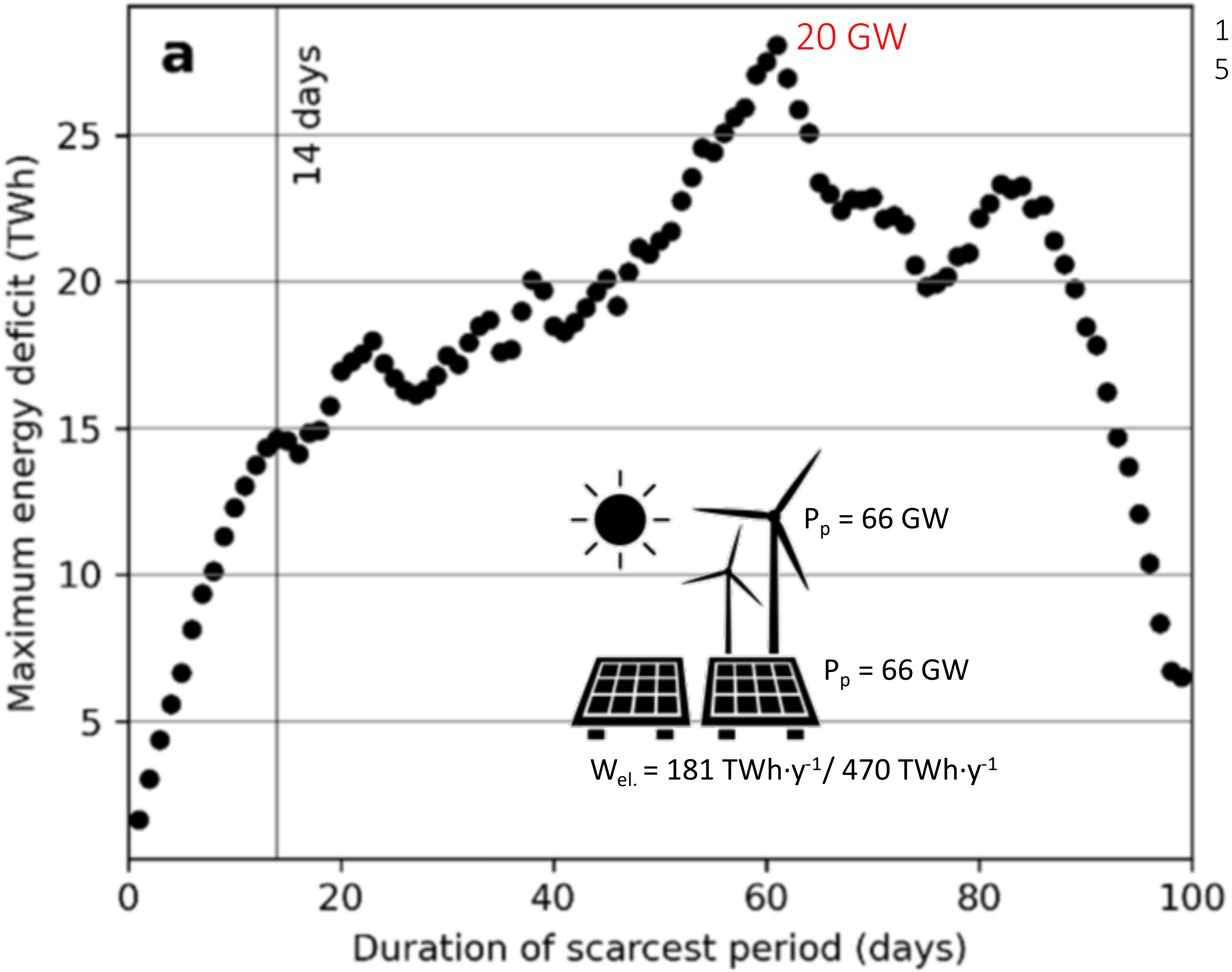
Current Energy Supply in Switzerland (2020)



Seasons in Switzerland



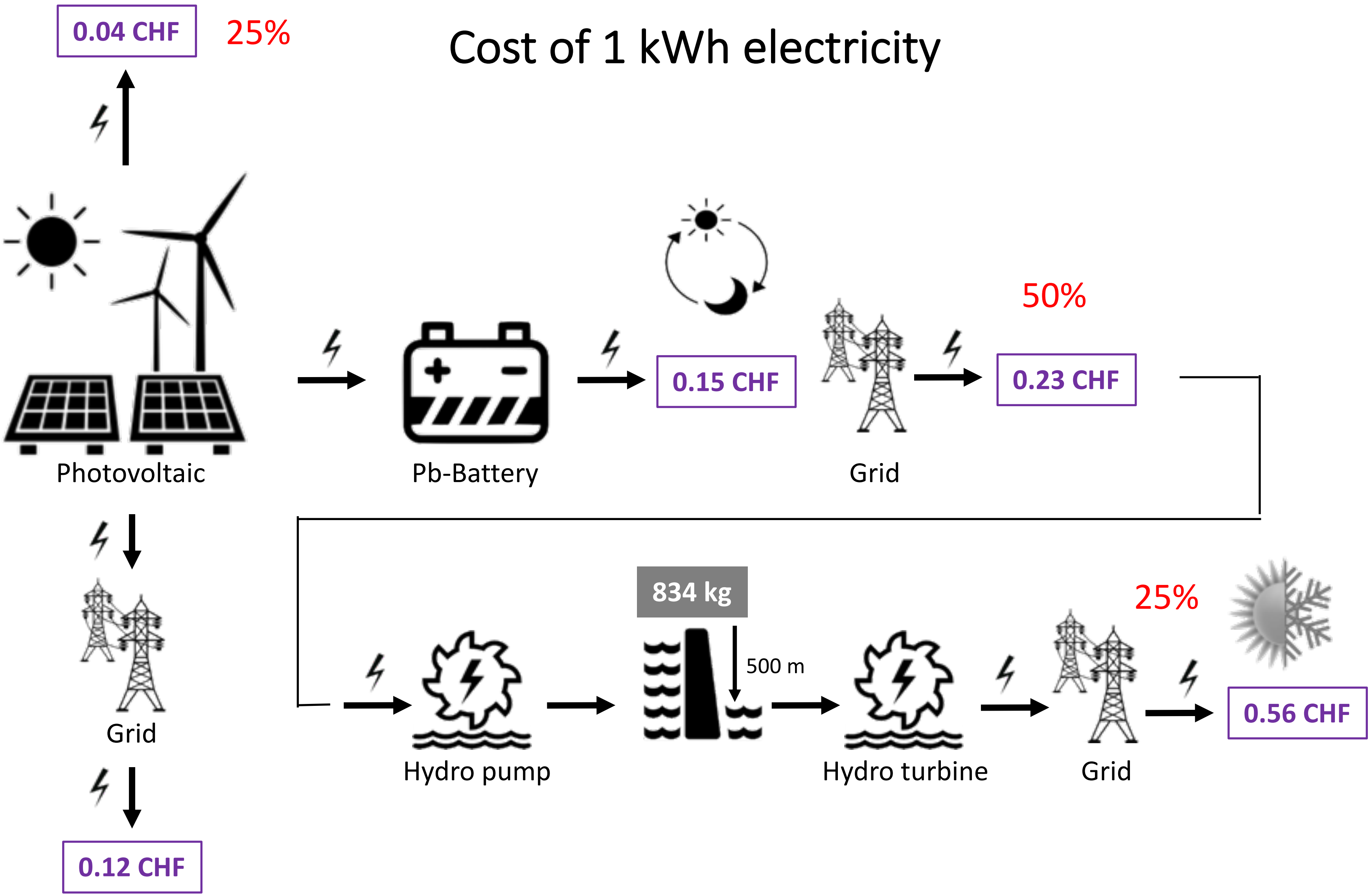
Renewable energy storage



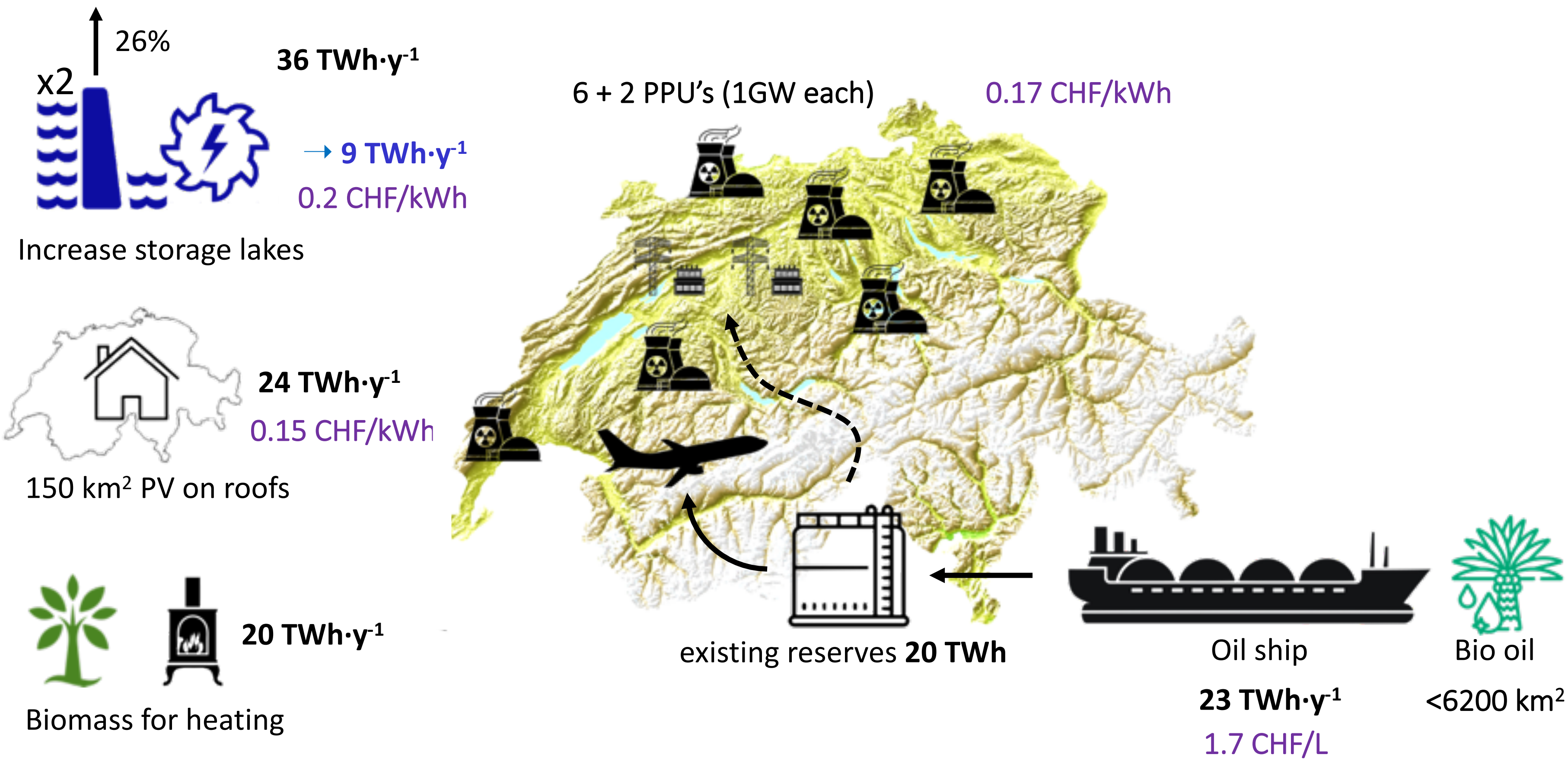
150 GW$_p$ installed
53 GW avg. Power

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

Renewable electricity on demand



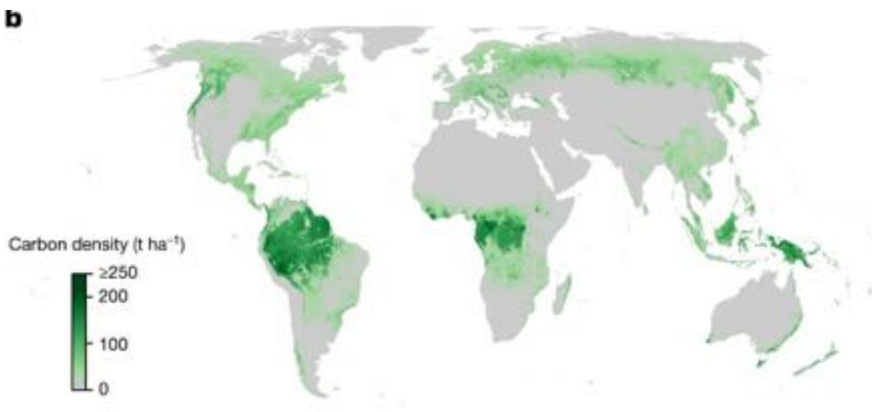
Renewable solutions (example)

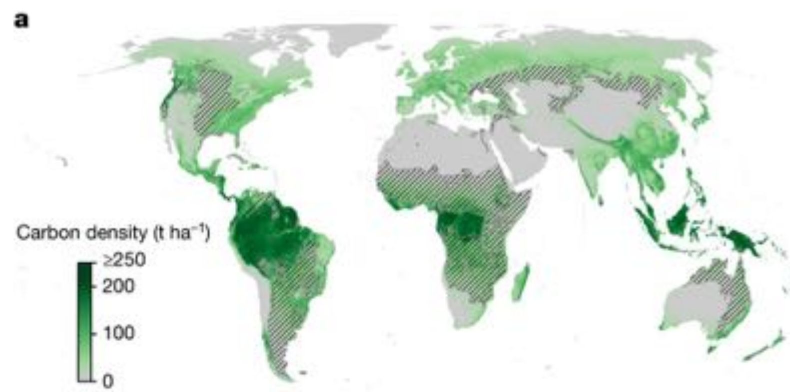


Carbon sinks and palm oil production

At present, global forest carbon storage is markedly under the natural potential, with a **total deficit of 226 Gt** (model range = 151–363 Gt) in areas with low human footprint. [1]
With 142 oil palm trunk (OPT) available per ha of plantation land and a replanted area of 100,550 ha in 2017, the estimated dry weight of OPT (**74.48 t ha^{-1}**) generated amounted to a total of 7.49 Mt [2]. 4.0 t·ha^{-1}·y^{-1} palm oil produced and the oil plants are replanted every 20 years.

30 kg oil·y^{-1} per tree with 524 kg dry biomass





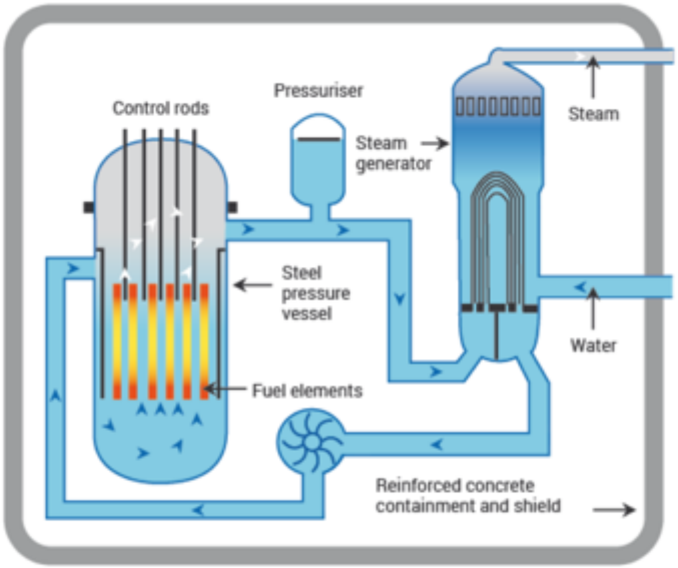
226 Gt palm tree produce 13 Gt oil·y^{-1} the current world fossil energy demand

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

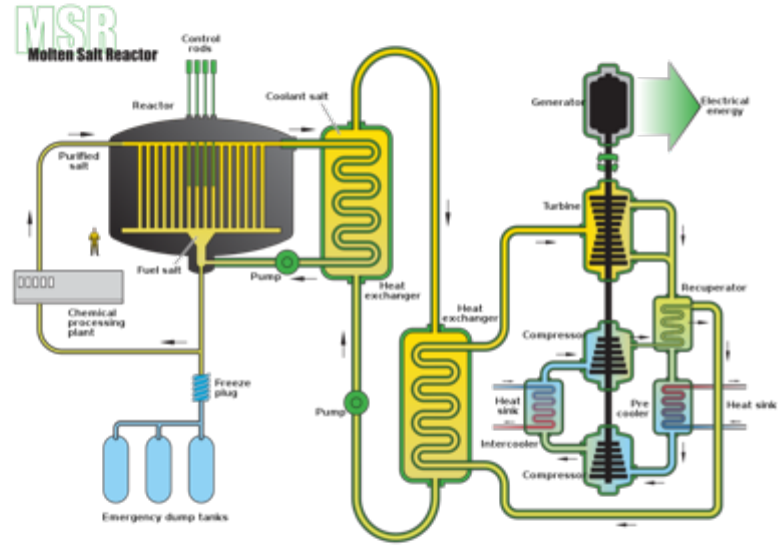
Nuclear reactors

Future

Uranium fission reactor



Thorium molten salt breading reactor



Disadvantages:

Limited uranium reserves (6% for 100 years)
Danger of core meltdown
Long-lived isotopes (Pu)
low efficiency (25%)
limited heat use
Nuc final repository. Waste
Small Modular Reactors (SMR)

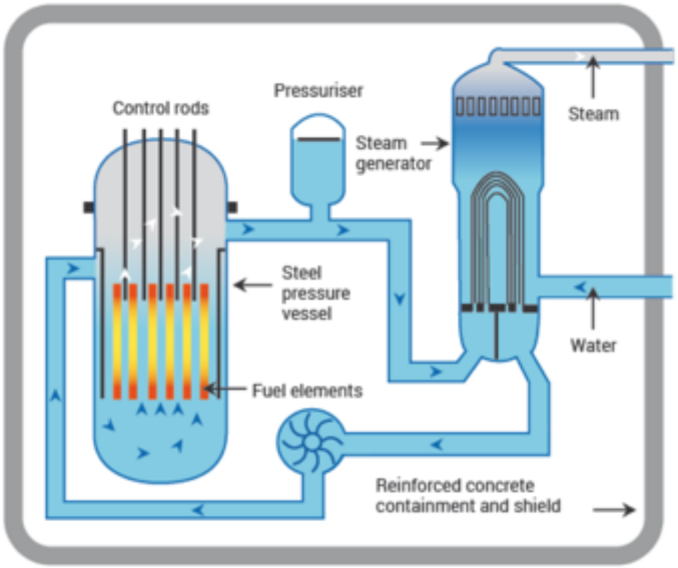
Advantages:

Large thorium reserves (use of nuclear waste, 95% is fuel)
No core meltdown possible
No long-lived isotopes
higher T, higher efficiency (>25%)
Using heat for heating
Molten Salt Reactor (MSR)

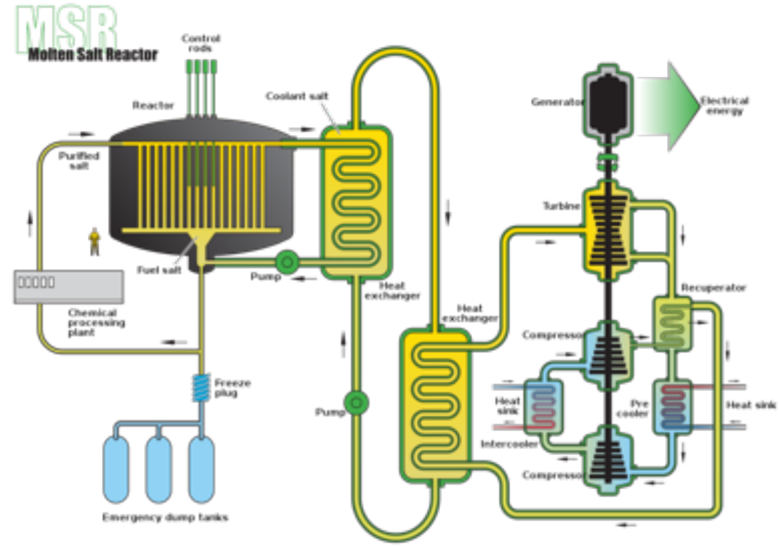
Nuclear reactors

Future

Uranium fission reactor



Thorium molten salt breading reactor



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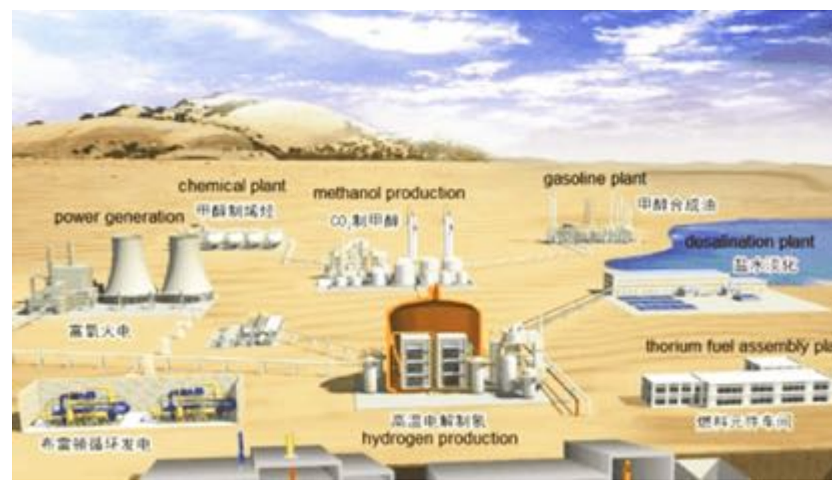
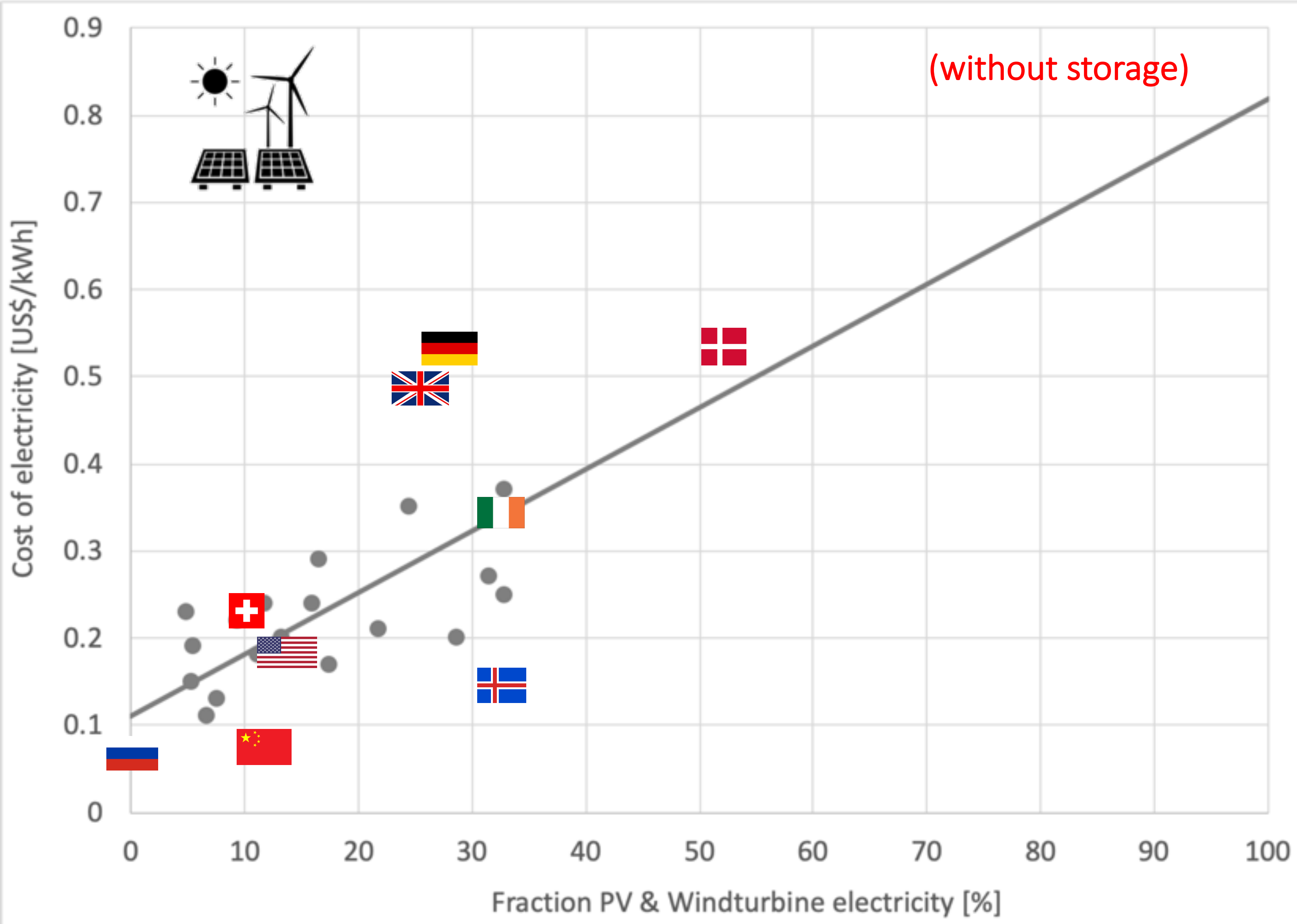


TMSR-LF1 (2 $MW_{therm.}$) construction 2018 - 2023, Wuwei city, Gansu province, China, operated since July 2023

Cost of electricity with PV and wind (2023)



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

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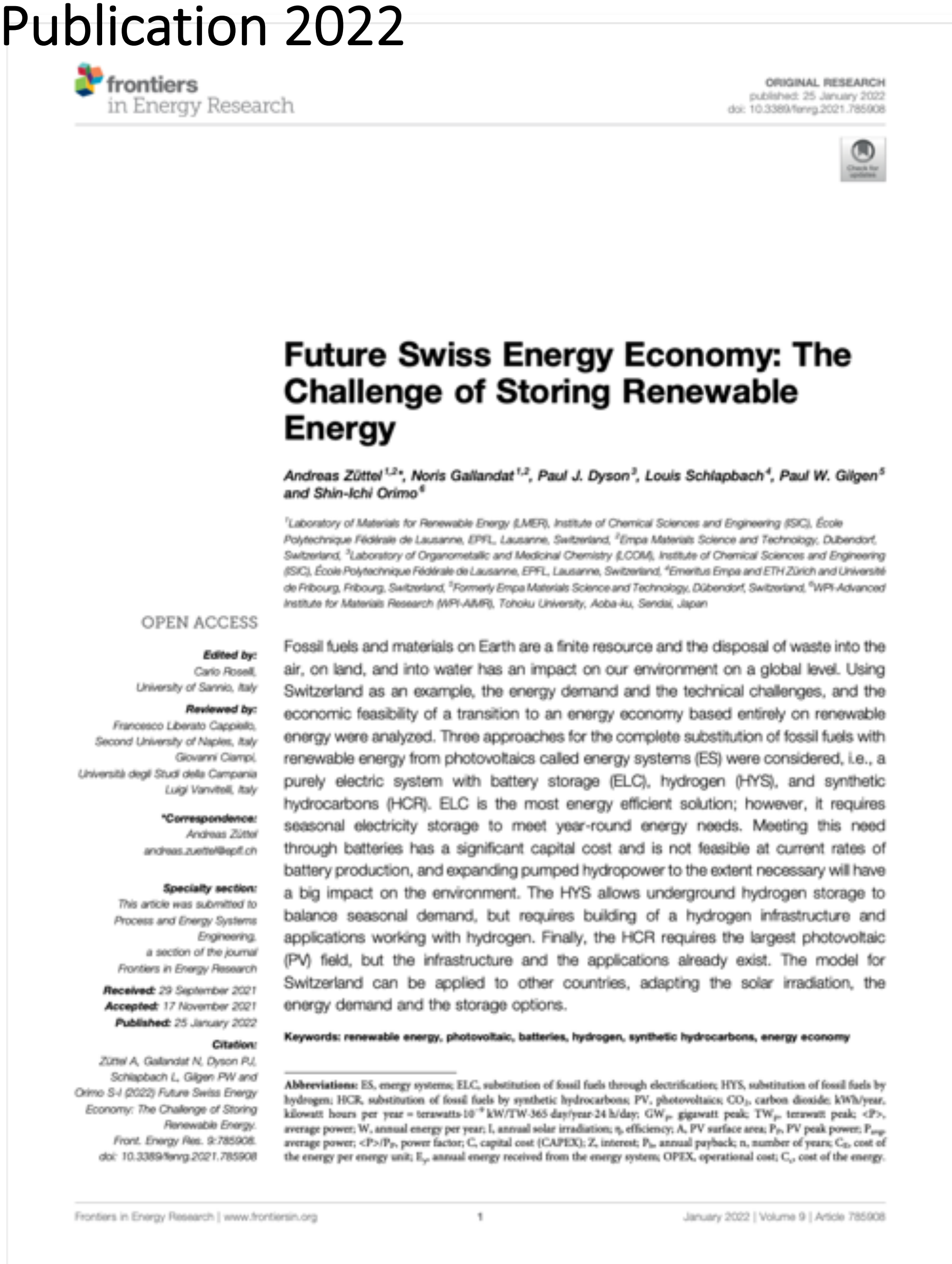
frontiers in Energy Research

ORIGINAL RESEARCH
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Future Swiss Energy Economy: The Challenge of Storing Renewable Energy

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[1]Laboratory of Materials for Renewable Energy (LMER), Institute of Chemical Sciences and Engineering (ISIC), École Polytechnique Fédérale de Lausanne, EPFL, Lausanne, Switzerland, [2]Empa Materials Science and Technology, Dübendorf, Switzerland, [3]Laboratory of Organometallic and Medicinal Chemistry (LCOM), Institute of Chemical Sciences and Engineering (ISIC), École Polytechnique Fédérale de Lausanne, EPFL, Lausanne, Switzerland, [4]Emeritus Empa and ETH Zürich and Université de Fribourg, Fribourg, Switzerland, [5]Formerly Empa Materials Science and Technology, Dübendorf, Switzerland, [6]WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Aoba-ku, Sendai, Japan

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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_{in}, 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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Prof. Dr. Louis SCHLAPBACH


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Andreas ZÜTTEL, Noris GALLANDAT, Paul J. DYSON, Louis SCHLAPBACH, Paul W. GILGEN, Shin-Ichi ORIMO, “Future Swiss Energy Economy: the challenge of storing renewable energy”, Frontiers in Energy Research: Process and Energy Systems Engineering, 9 (2022), https://doi.org/10.3389/fenrg.2021.785908

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