Flexibility provision in the Swiss integrated power, hydrogen, and methane infrastructure

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sweet swiss energy research for the energy transition

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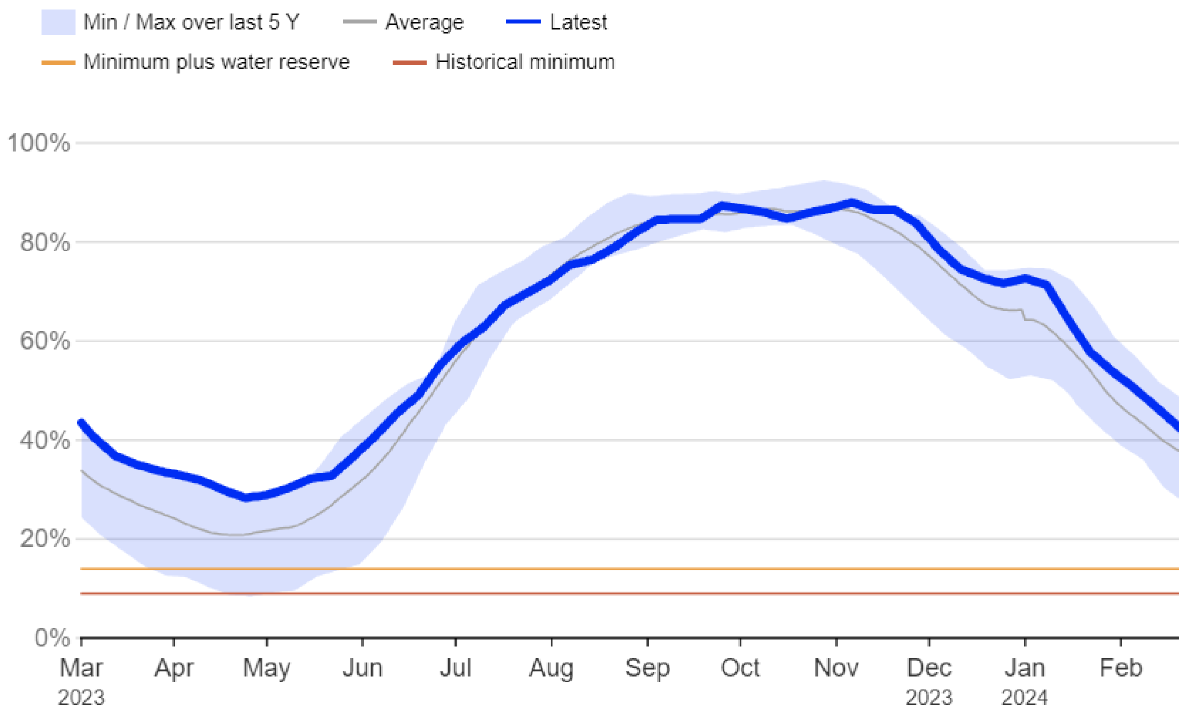
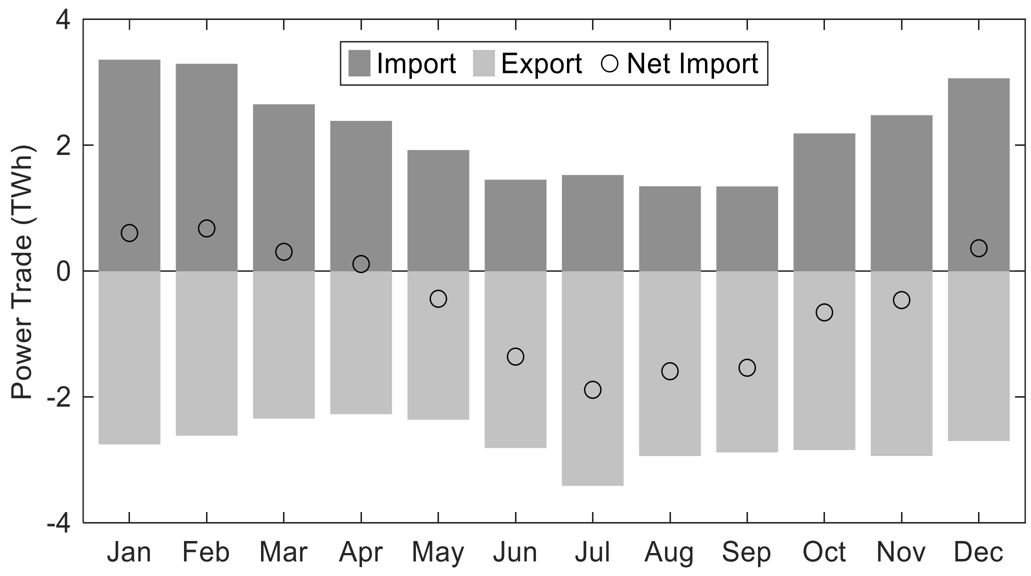
Swiss power system will need additional flexibility

- Today’s seasonal supply-demand mismatch is balanced by hydropower and power trade.



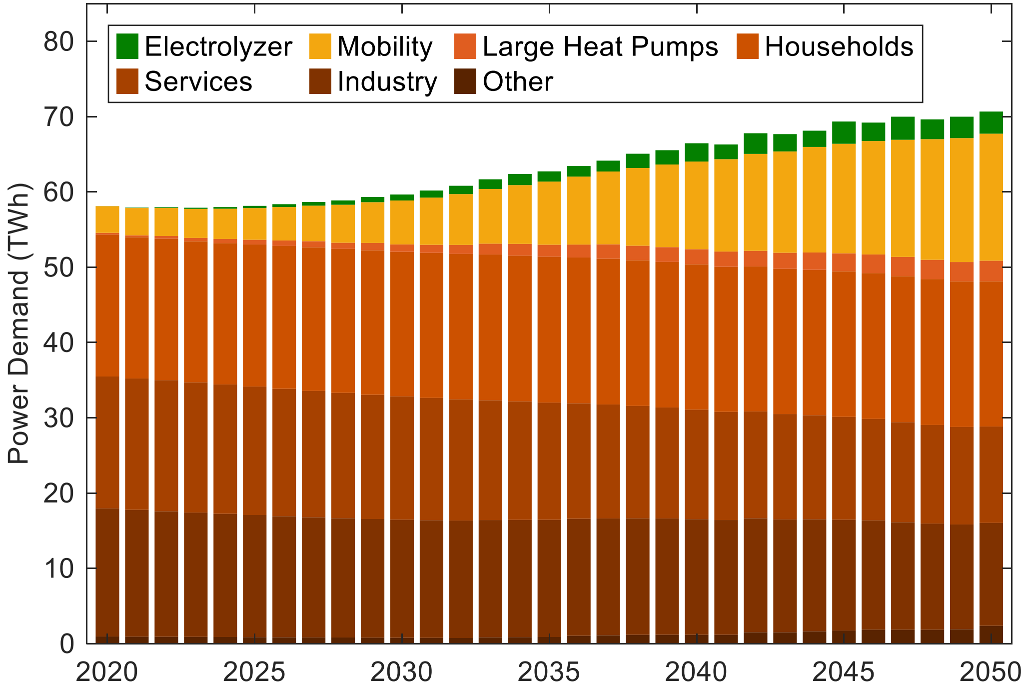
Source: Füllungsgrad der Speicherseen 2024, BFE



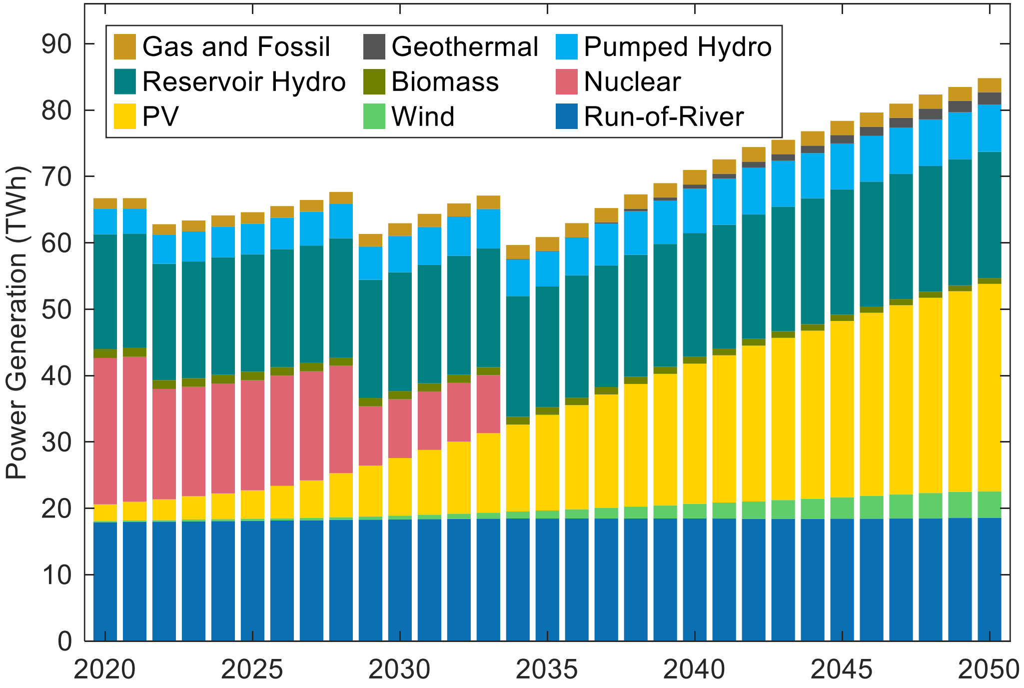
Source: Energieuebersicht Schweiz 2023, Swissgrid

Swiss power system will need additional flexibility

- Today’s seasonal supply-demand mismatch is balanced by hydropower and power trade.
- Electrified heating and mobility worsen the winter deficit.
- Nuclear phase-out and PV buildout heighten seasonal and intraday imbalance.



Source: Energieperspektiven 2050+, BFE, 2022



Source: Energieperspektiven 2050+, BFE, 2022

Various flexible resources

Storage

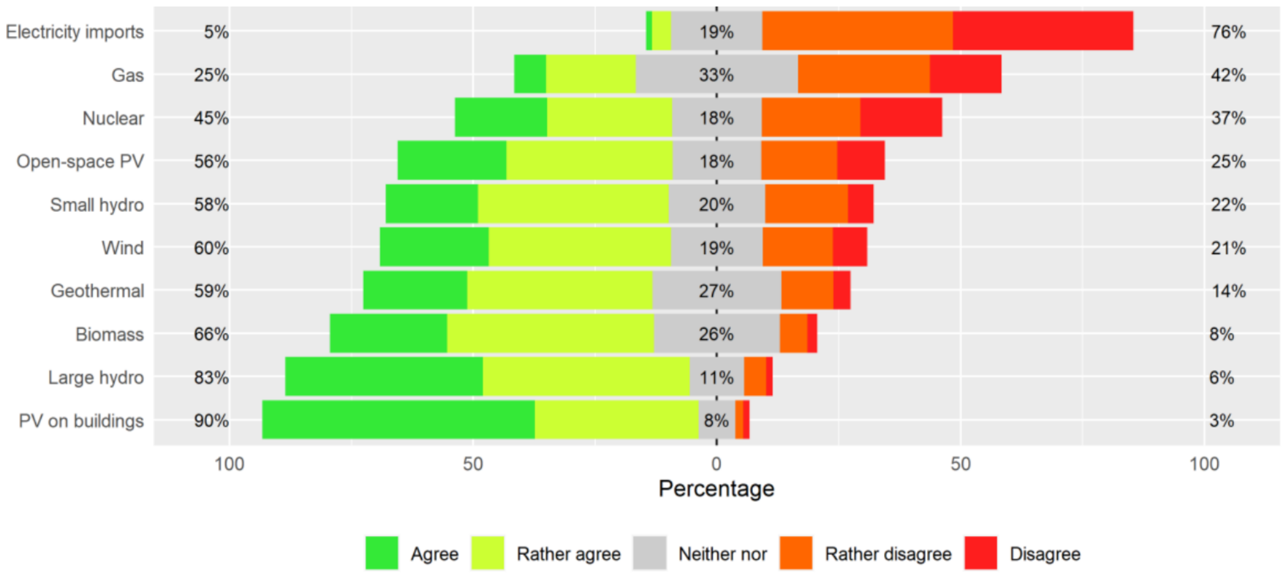
Reservoir and pumped hydro
Fuel storage, e.g., methane, hydrogen
Batteries

Energy trade

Power trade: low acceptance in Switzerland
Fuel imports: Uncertain availability and price

Renewables with high winter yield

Alpine PV
Wind



Source: Population Survey, EDGE Highlights Report Year 2, 2023

Sector coupling

Power generation from gaseous fuels
Power-to-gas

Demand flexibility

Demand shifting, e.g., electric mobility and heating
Price elasticity

Research scope

- **Q1:** What is a cost-effective portfolio considering flexibility needs across time scales?
- **Q2:** What are infrastructure needs under stringent energy trades, i.e., limited power trades and fuel embargos?

Objective: Examine flexibility provision across intraday to seasonal time scales in the sector-coupled Swiss energy system under various energy trade scenarios

RRE Reliability & Risk Engineering

Energy Science Center

- We[1] address research gaps using
  - high spatiotemporal resolution
  - thorough flexibility representation.

[1] Akbari *et al.*, Working Paper

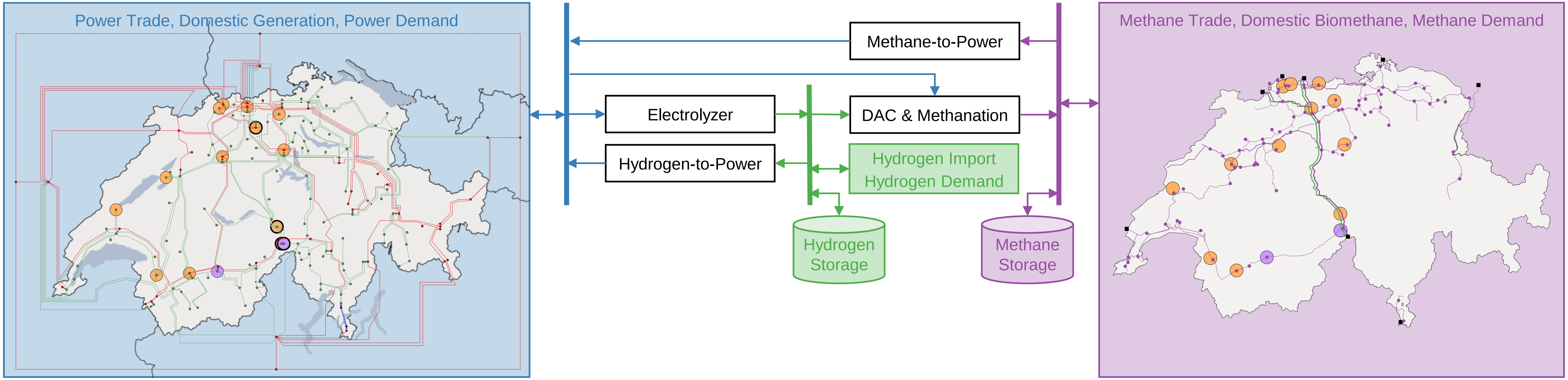
Agenda

- **Energy system planning methodology**
- Operations under reference energy trades
- Impact of stringent energy trades on investments and operations
- Role of hydrogen and methane technologies across various trade scenarios
- Conclusions and outlook

Energy system planning methodology

Investment and hourly operations optimization in 2050

- Swiss power transmission network and aggregated neighboring countries, modeled in Nexus-e[1]
- Swiss gas transmission network, modeled in GasNet[2]
- PtGtP[3] technologies and gaseous storages (i.e., tanks and caverns)



[1] Gjorgiev *et al.*, 2022

[2] Akbari *et al.*, 2023

[3] Power-to-Gas-to-Power

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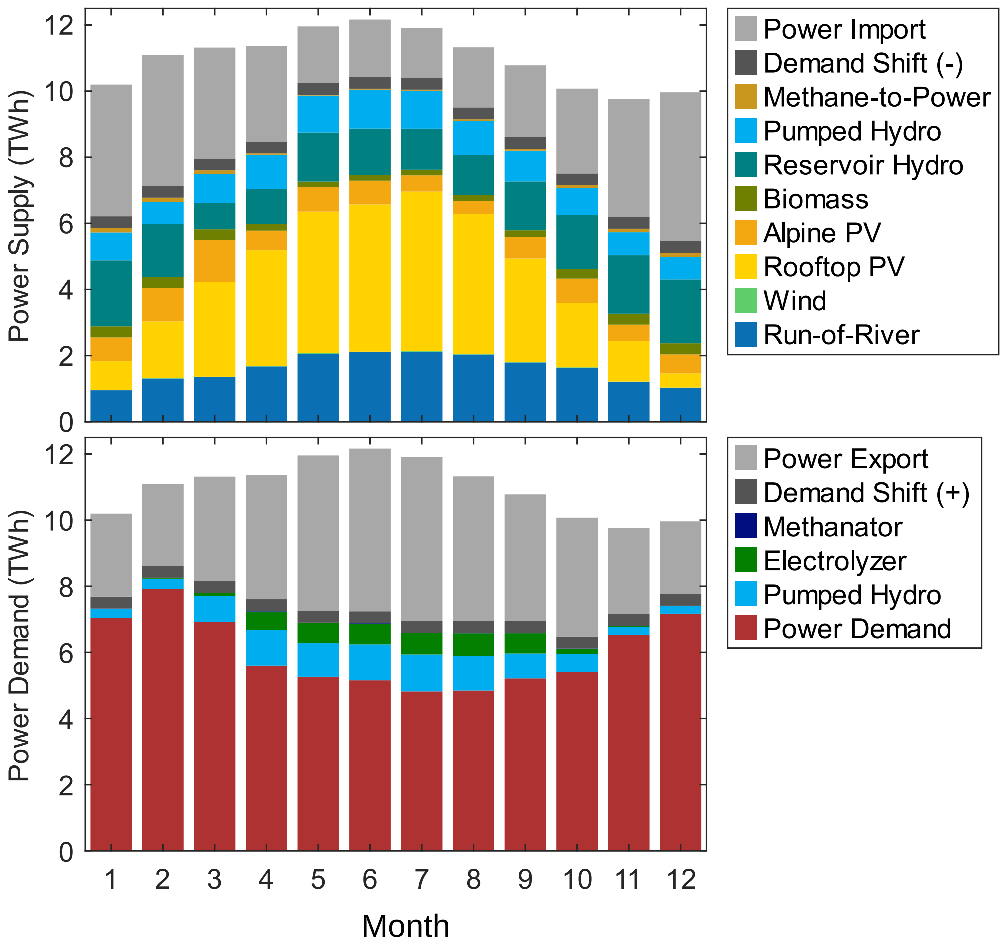
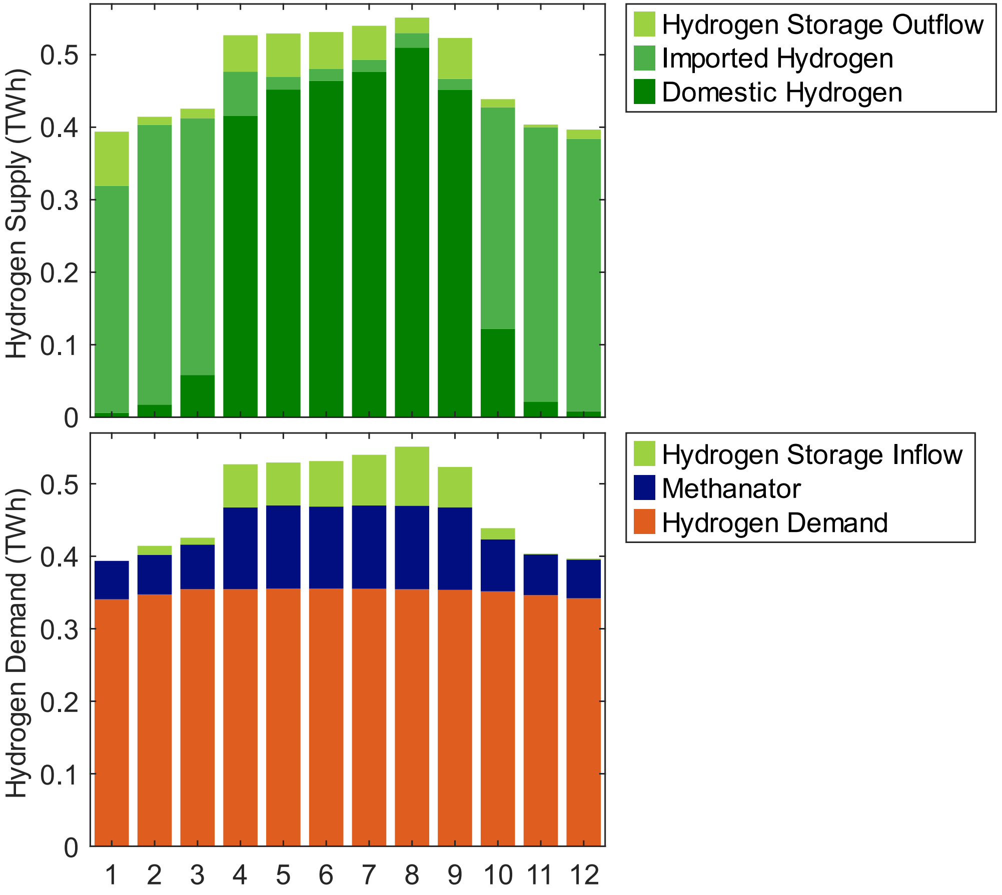
Power flexibility drivers and providers

- Seasonality of PV, run-of-river, and power demand
- Power supply from reservoir hydro, alpine PV, biomass, and methane-to-power concentrated in winter
- Pumped hydro and electrolyzers absorbing excess power in summer
- Intraday flexibility from demand shifting throughout the year
- Net imports in winter and net exports in summer

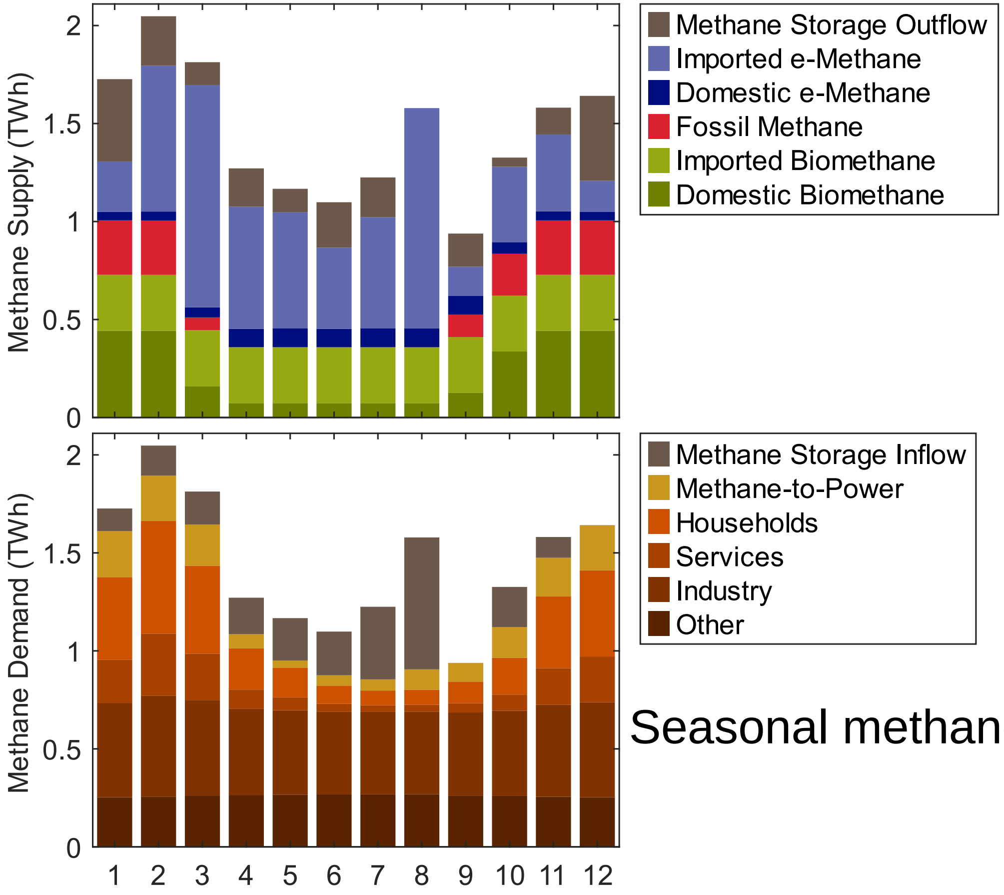


Seasonality propagation across sectors

Power-to-gas in summer



Hydrogen balance through imports and minor flexibility from storage and demand



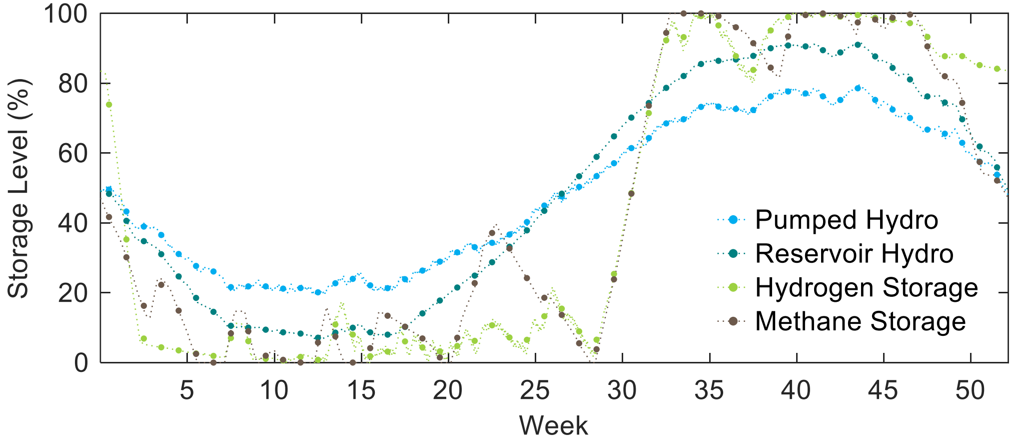
Seasonal methane demand

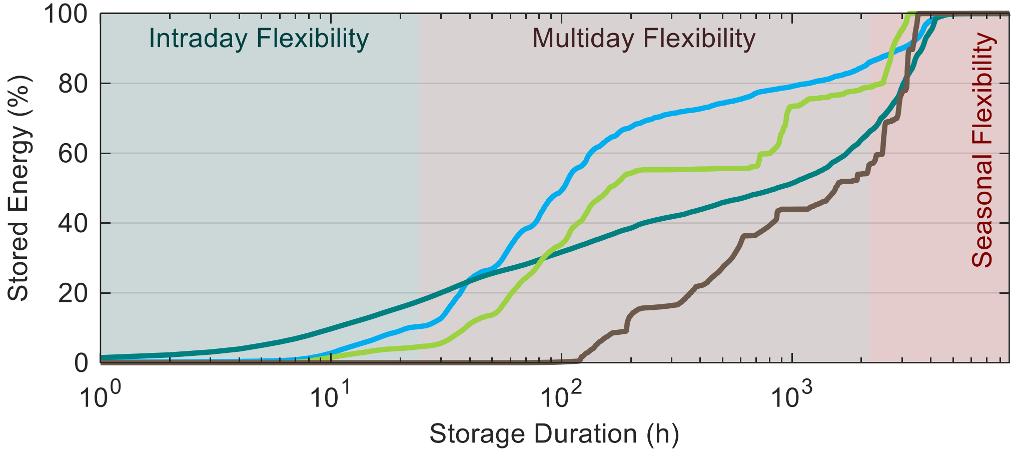
Methane-to-power in winter

Seasonal flexibility from domestic biomethane, fossil methane imports, and methane storage

Flexibility from storages across time scales

- Hydro and gaseous storages operate seasonally, with min and max levels in March and October.
- Pumped hydro and hydrogen storage with average storage durations of 29-36 days mainly provide multiday flexibility driven by variable renewable energy generation.
- Reservoir hydro has an average storage duration of 59 days, mainly driven by power demand fluctuations.
- Methane storage has an average storage duration of 70 days, driven by fluctuations in methane demand and e-methane import price.





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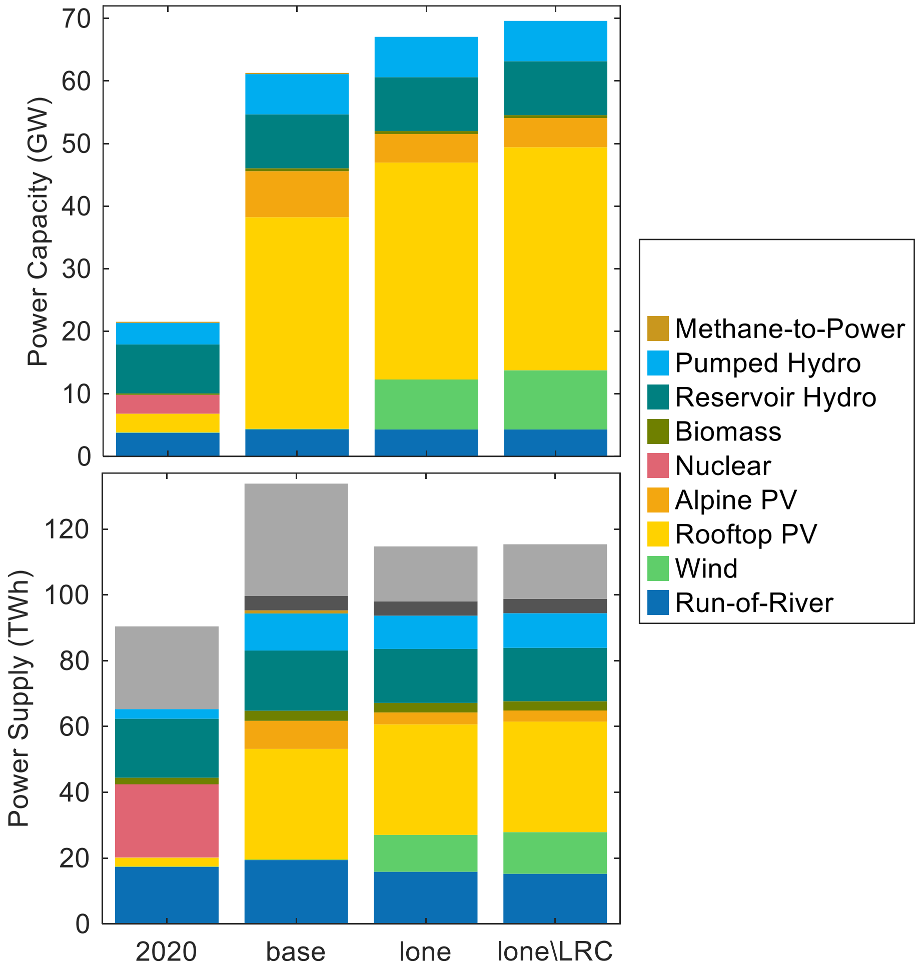
Scenarios

Scenario	Power NTC[1]	Fuel Import	Gaseous Storage
2020	99%	Fossil, nuclear	Only existing
base	100%	Fossil, renewable	Tank, cavern
lone	30%	Not allowed	Tank, cavern
lone\LRC[2]	30%	Not allowed	Tank

[1] Net transfer capacity
[2] Lined rock cavern

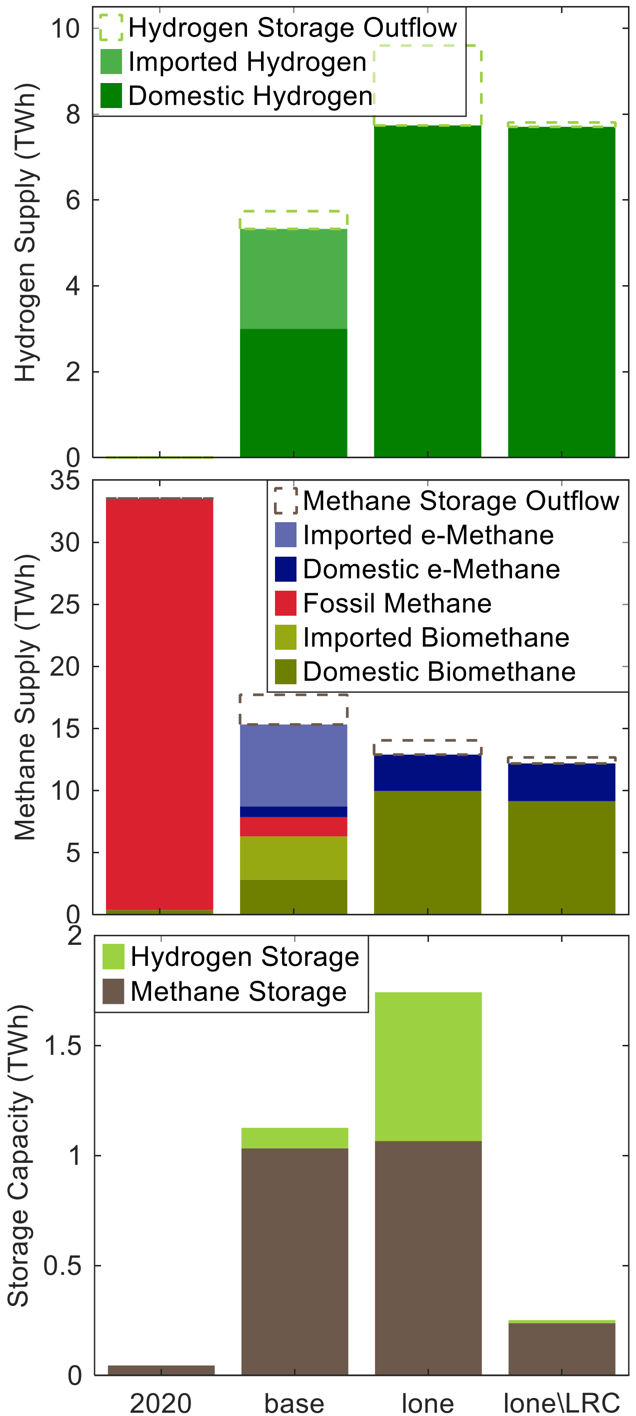
Limited power trade requires additional renewable capacity

- 6.7-to-8.0-fold expansion of variable renewable energies (VREs), i.e., PV, wind, and run-of-river, between 2020 and 2050
- Limited power trade favors winter-focused wind generation, increasing the wind capacity up to 9.5 GW.
- Higher VRE capacity under limited power export increases VRE curtailment from 7% to 14-17%.
- Domestic electricity-based fuels are too costly for power generation.



Fuel embargo drives domestic production

- Emerging hydrogen demand in 2050 requires imports and domestic production.
- Trade limitations favor electrolyzers running on excess power in summer.
- Emission limits in 2050 slash fossil methane imports.
- Fuel embargo boosts domestic biomethane and e-methane.
- Up to 1.7 TWh of cavern storage ensure winter gas supply in 2050.
- Excluding caverns reduces gaseous storage to 0.2 TWh.



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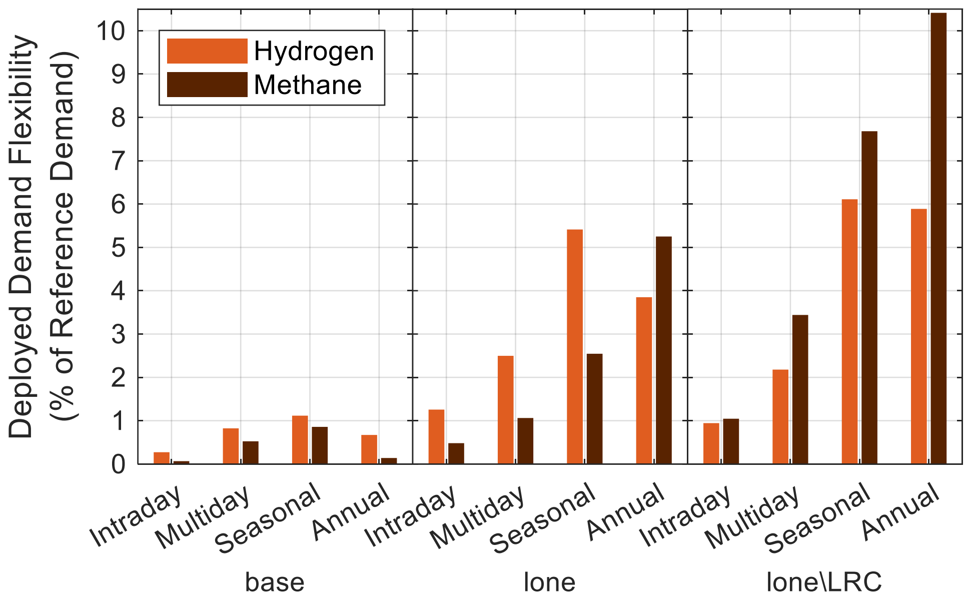
Fuel embargo drives demand flexibility deployment

- Hydrogen and methane demands contribute <1.1% to flexibility under reference energy trades.

- Fuel embargo reduces demand especially in winter, raising the seasonal and annual flexibility to 2.5%-5.4%.

- Without cavern storage, flexibility deployment rises to 5.9%-10.4%.



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Trade scenarios

e-Gas Import Price	Hydrogen (€/MWh)	e-Methane (€/MWh)
cheapest	45.0	65.0
cheap	82.6	111.7
reference	120.1	158.3
costly	157.7	205.0

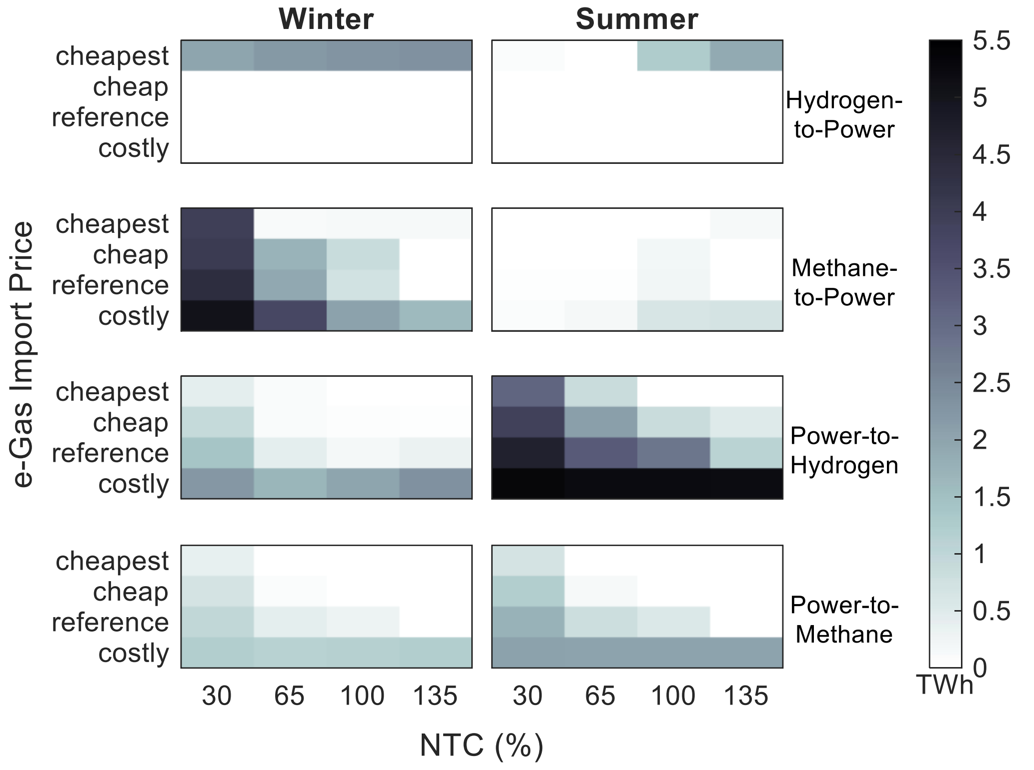
Trade scenarios

e-Gas Import Price				
cheapest				
cheap				
reference			base	
costly				
	30	65	100	135

NTC (%)

PtGtP conversion hinges on trade conditions

- Hydrogen-to-power supplying power demand in winter for hydrogen import prices below 70 €/MWh
- Methane-to-power contributing to winter power supply under restricted power imports
- Power-to-hydrogen using excess power in summer under limited power exports to displace costly hydrogen imports
- Power-to-methane sees maximal use under limited power exports and costly e-methane imports

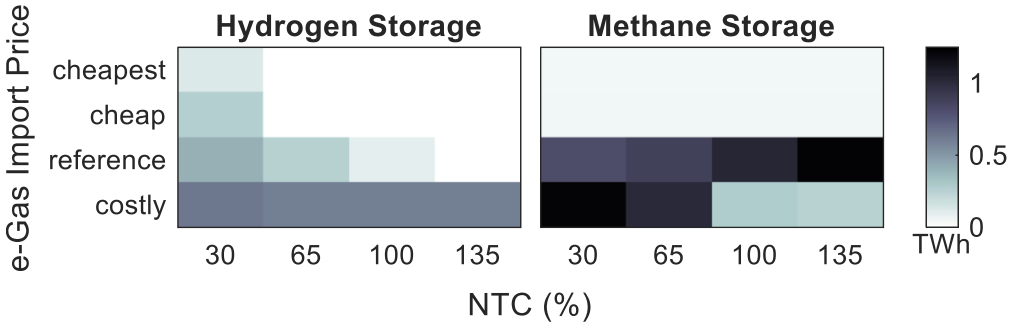


Little gaseous storage under cheap fuel imports

- Up to 0.6 TWh of hydrogen storage to avoid costly hydrogen imports in winter

- Up to 1.2 TWh of methane storage to leverage the seasonal price spread for e-methane import prices above 150 €/MWh

- Due to cost reasons, methane storage preferred over hydrogen storage in the power-to-methane pathway



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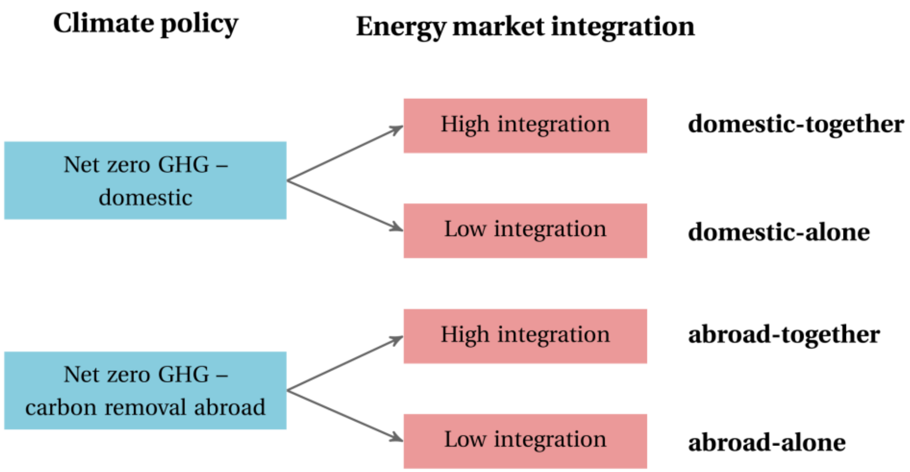
Conclusions

	Base	Lone
• Significant capacity expansion of PV, wind, run-of-river by 2050	6.7-fold	7.6-fold
• Limited power exports increase variable renewable curtailment.	7%	14%
• Power-to-gas can run on excess power in summer.	4.2 TWh_e/y	10.8 TWh_e/y
• Gas turbines burn imported fuels to supply power in winter.	0.9 TWh_e/y	0 TWh_e/y
• Fuel embargo reduces final gas demand in winter.	17.8 TWh_{th}/y	17.0 TWh_{th}/y (-4.7%)
• Fuel embargo favors gaseous storage.	1.1 TWh_{th}	1.7 TWh_{th}
• Fuel embargo prolongs gaseous storage duration.	36-70 days	69-182 days

- Geological viability of caverns guide storage and power-to-gas placement.
- Power network constraints and net transfer capacities guide the placement of power generation, power-to-gas, and network expansion.

Outlook

- Further alignment with CROSS scenarios and values



- Use Euro-Calliope to obtain boundary conditions, e.g., Swiss energy demands, power generation portfolio in neighboring countries

- Conduct sensitivity analysis with respect to impactful parameters

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