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How to design the future electricity mix of Côte d'Ivoire ?

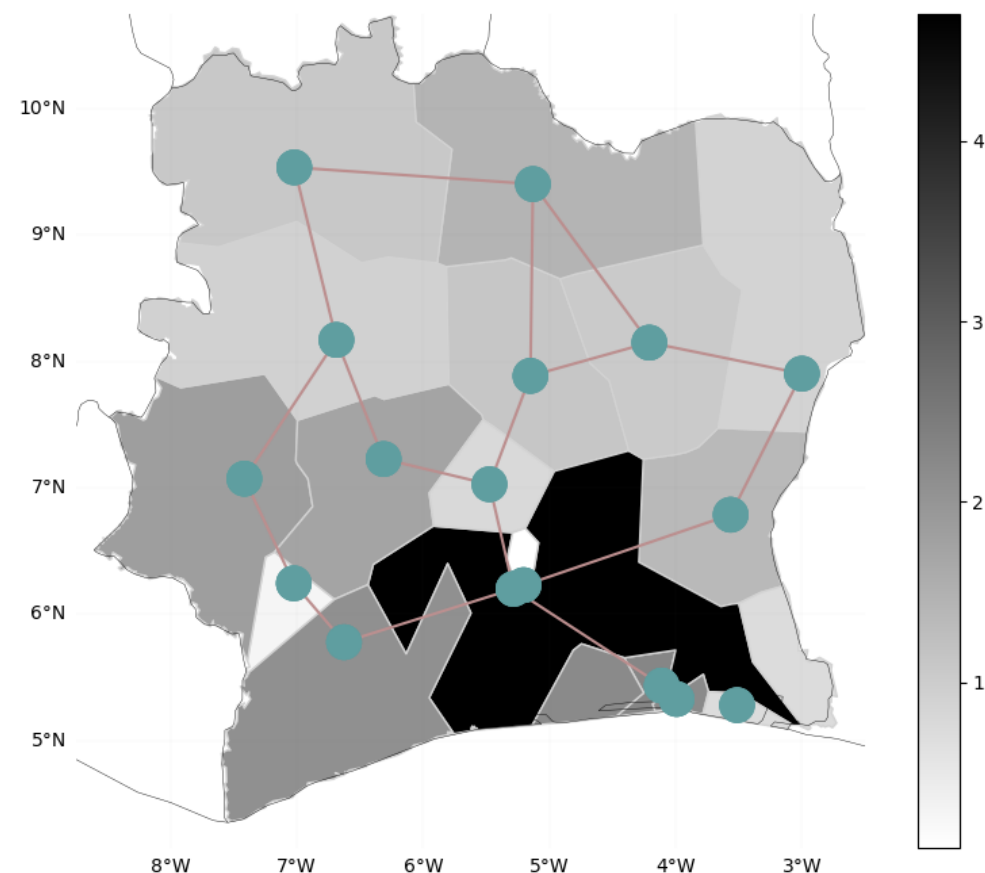
Context :

- Rapid growth in demand for electricity in West Africa
- Multiple resources available (hydro, biomass, solar, gas)
- By 2030, -30% CO₂ emissions & renewable energy supply > 45%

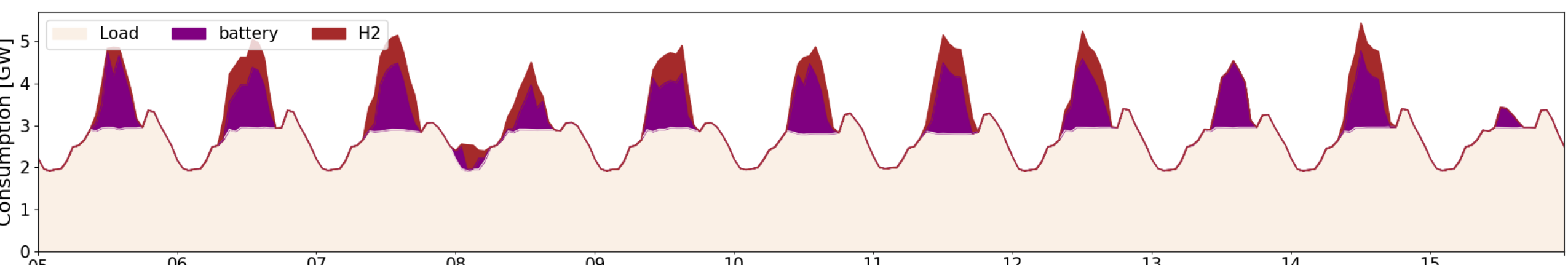
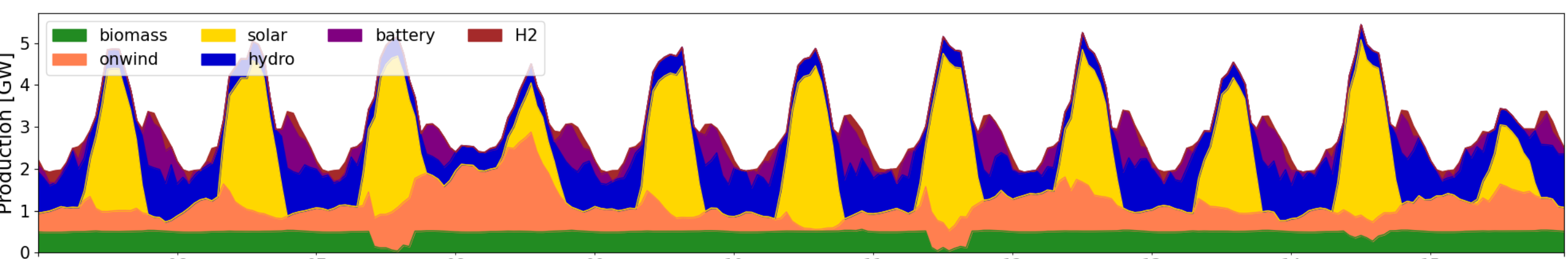
Research questions :

- What are the possible pathways for the electricity mix of Côte d'Ivoire ?
- Should we focus on cost optimization and direct CO₂ emissions only ?
- How reliable is the electricity from these different mixes ?

Usual design of the electricity grid:



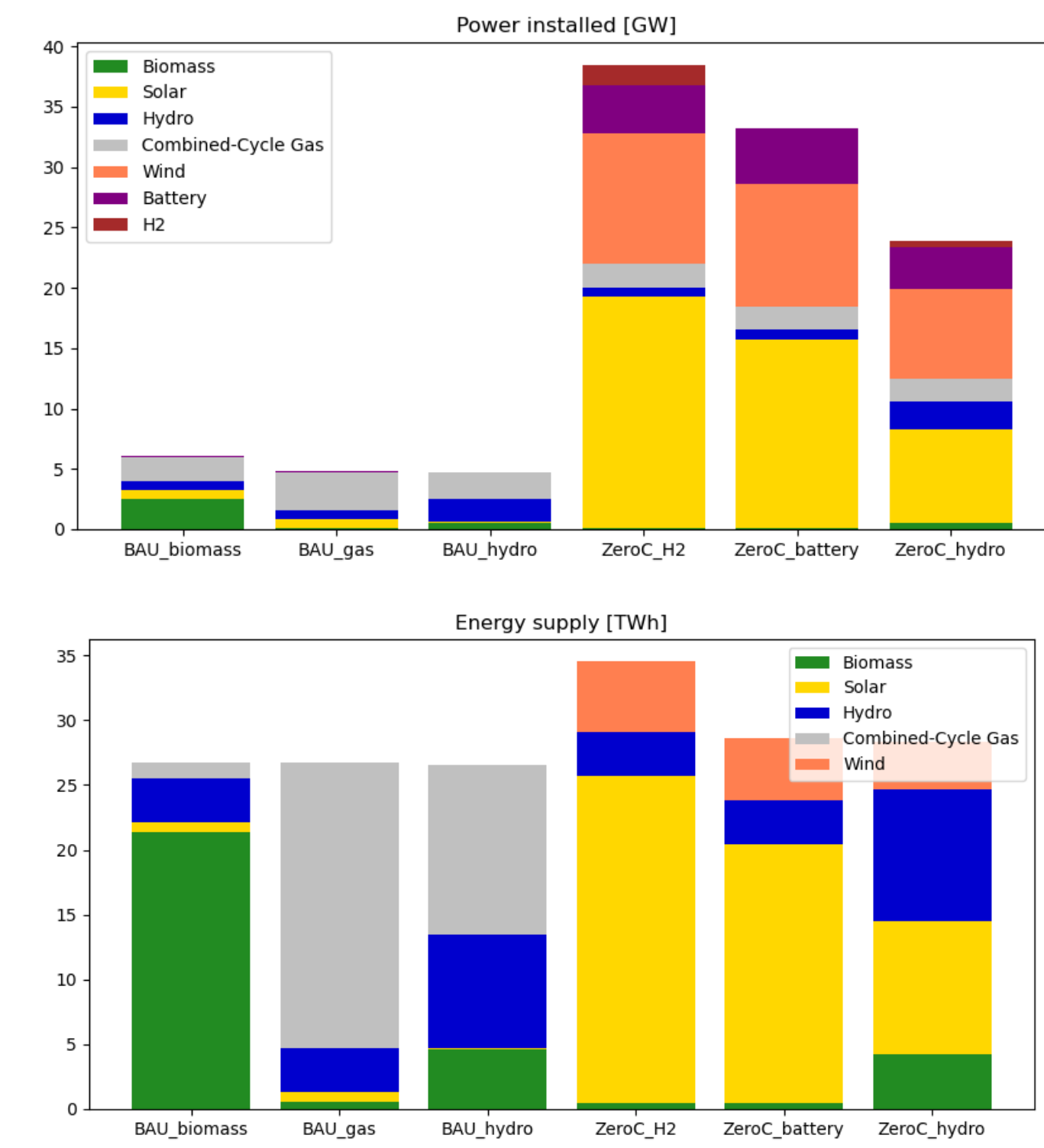
- Open-source model PyPSA
- 1-hr resolution over one year
- Exogenous electric demand (IEA 2040)
- Existing and planned plants
- Solar and wind potential from ERA5
- ADHI database for hydropower



Sources:
 Hersbach H, Bell B, Berrisford P, et al. The ERA5 global reanalysis. *Q J R Meteorol Soc*. 2020; 146: 1999–2049. <https://doi.org/10.1002/qj.3803>
 Eklou et al., Long-term variability in hydrological droughts and floods in sub-Saharan Africa: New perspectives from a 65-year daily streamflow dataset. *Journal of Hydrology*, Volume 613, Part A, 2022, 128359, ISSN 0022-1694, <https://doi.org/10.1016/j.jhydrol.2022.128359>.
 Parzen et al., "PyPSA-Earth: A new global open energy system optimization model demonstrated in Africa", 2023. <https://doi.org/10.1016/j.apenergy.2023.12109>.
 Africa Energy Outlook 2019, International Energy Agency <https://www.iea.org/reports/africa-energy-outlook-2019>

Least-cost optimization for 6 scenarios:

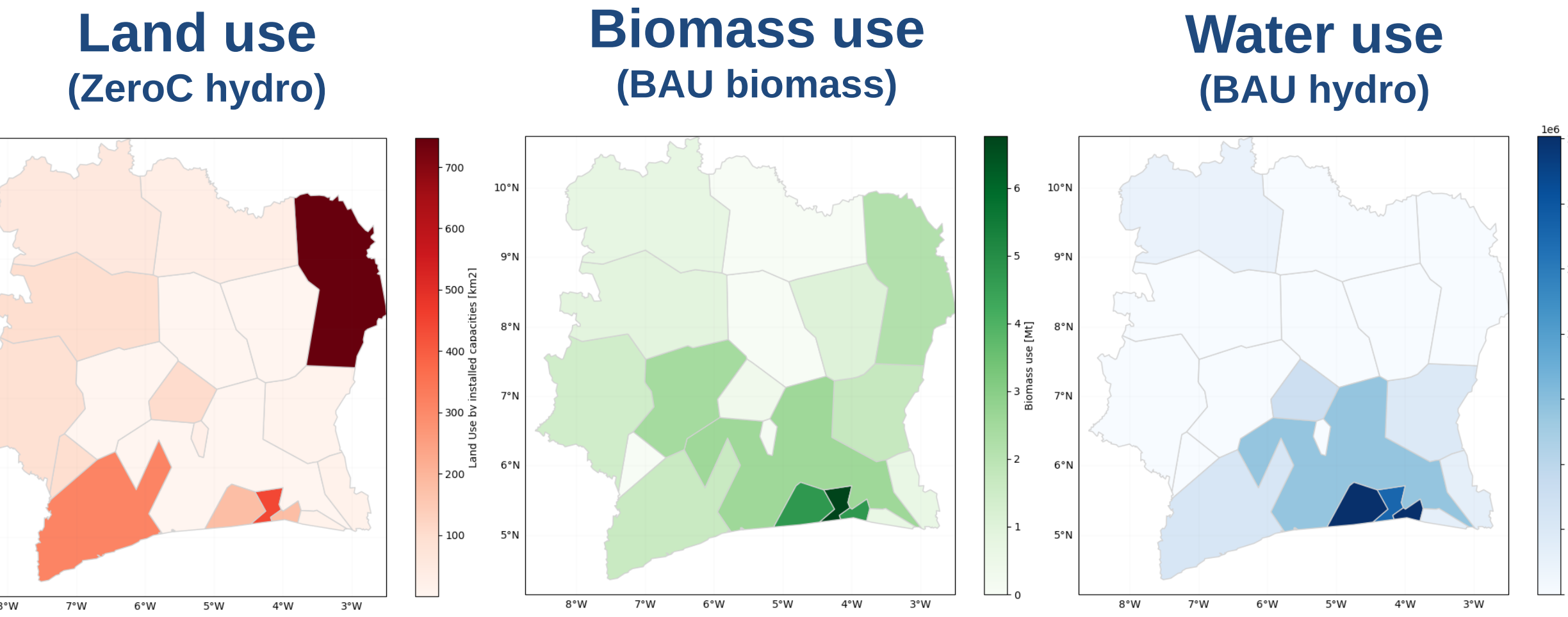
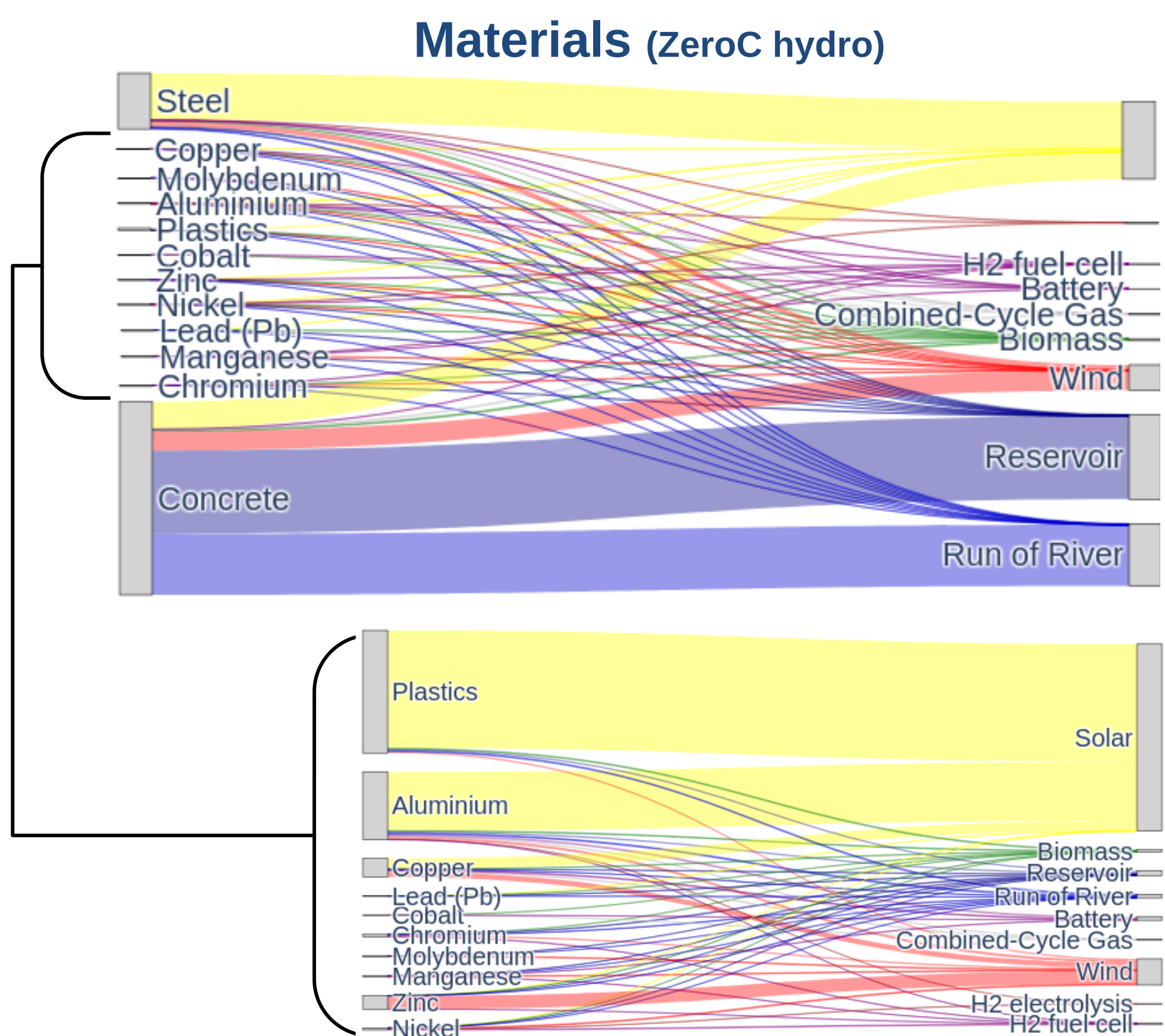
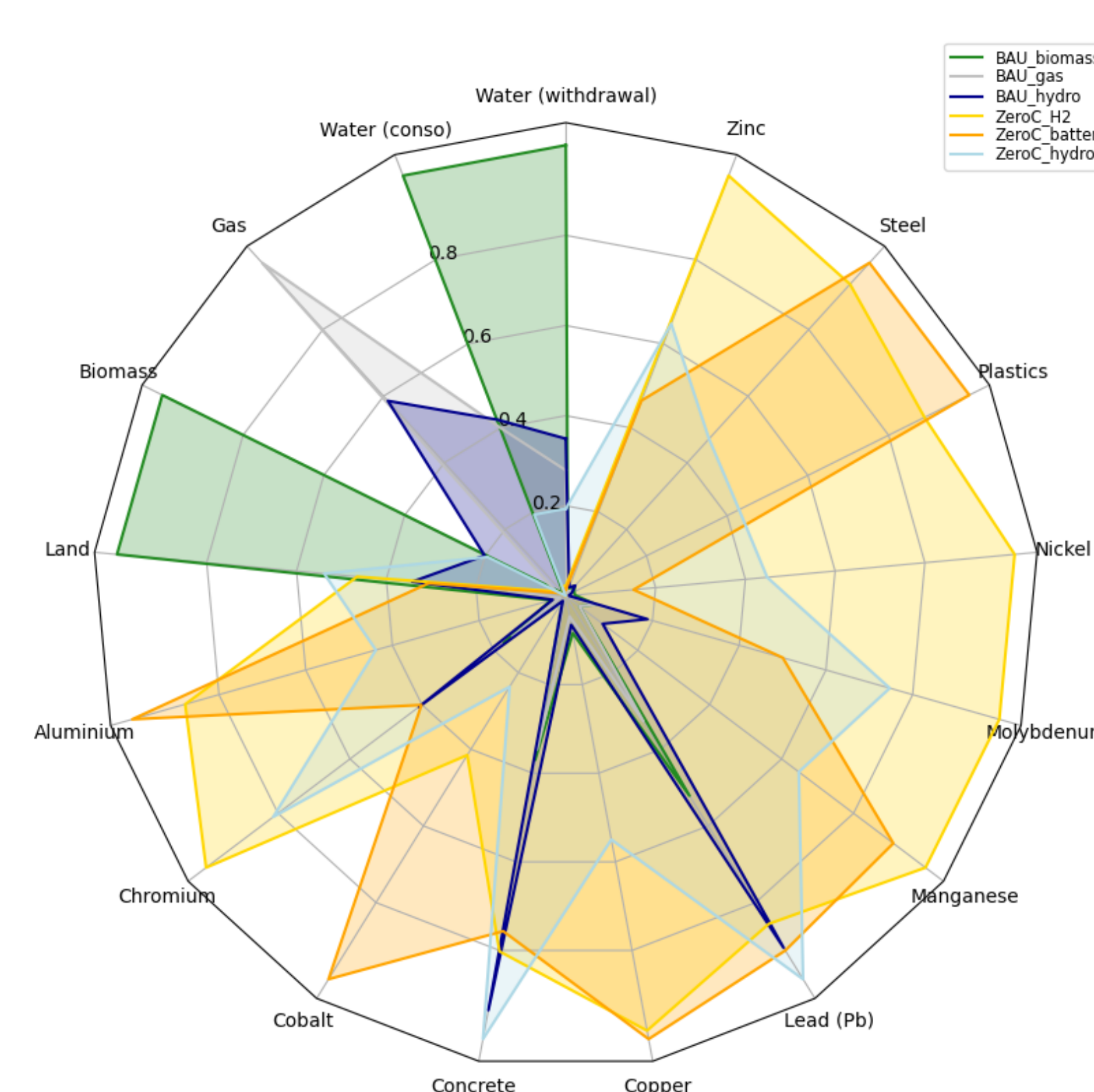
Scenario	BAU biomass	BAU gas	BAU hydro	ZeroC H2	ZeroC battery	ZeroC hydro
Biomass	Without limit	Existing only	Existing + planned	Existing only	Existing + planned	Existing + planned
CCGT	No limit					
Solar	Limited by the available area					
Wind	Limited by the available area					
Hydro	Existing only	Existing + planned	Existing only	Existing only	Existing + planned	Existing + planned
Battery	No limit					
H2	No limit			No H2	No H2	No limit
CO ₂ limit	No			Yes		
LCOE [\$/kWh]	0.04	0.06	0.06	0.24	0.27	0.14
CO ₂ [g/kWh]	2	324	190	0	0	0



- Large variations of LCOE and CO₂ emissions
- High sensitivity to CO₂ limit
- Mostly one dominant source for each scenario

- Growing rate of installed capacities ?
- Demand sensitivity ?
- On-grid electricity only ?
- How to implement these mixes ?

Resources consumption :



- Every scenarios consume resources
- Diversified mix allows trade-offs in resource use
- Carbon footprint : every scenario emits CO₂
- Should consider geographical distribution of impacts

Carbon footprint

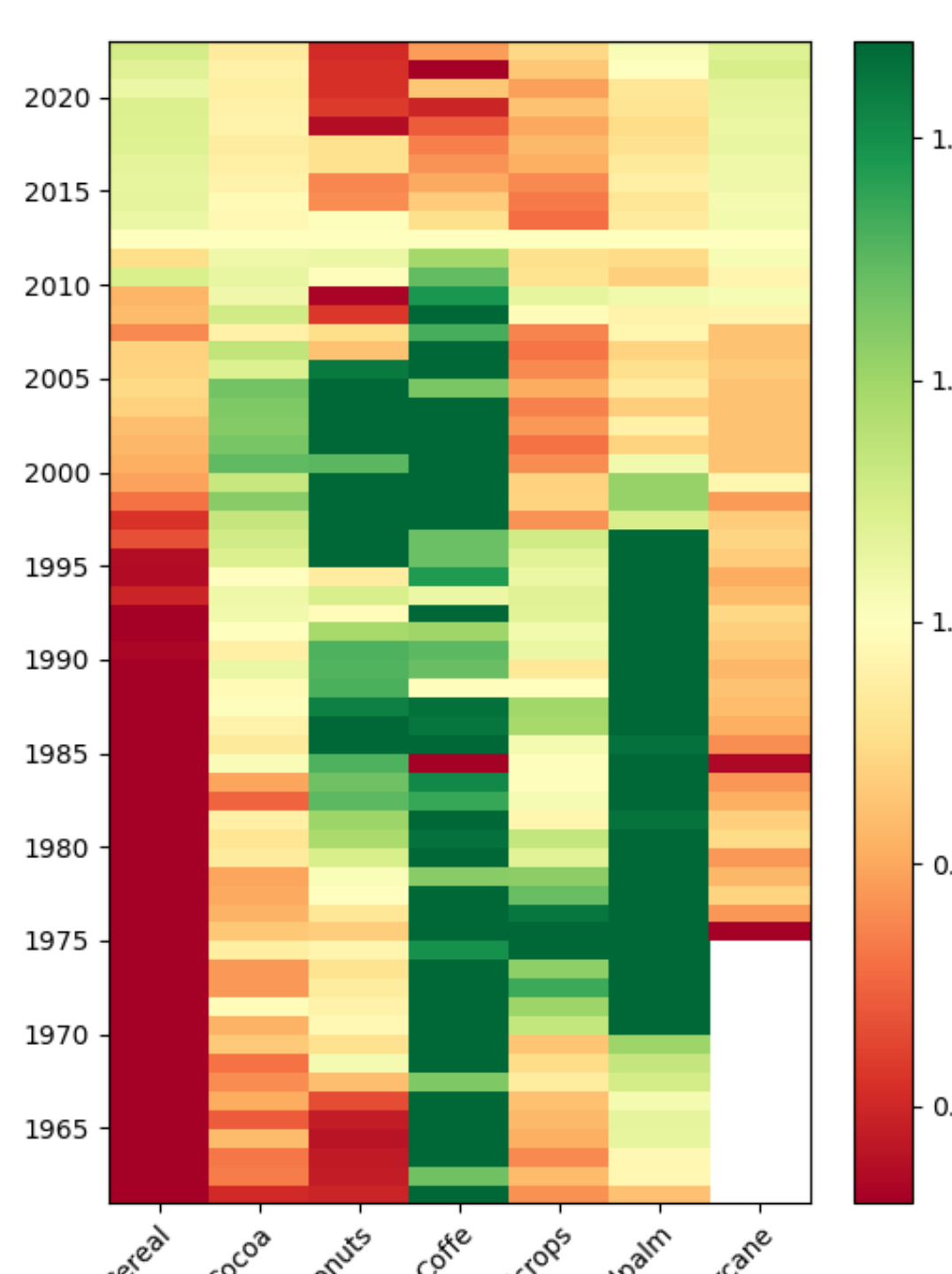
Scenario	BAU biomass	BAU gas	BAU hydro	ZeroC H2	ZeroC battery	ZeroC hydro
Direct CO ₂ [g/kWh]	2	324	190	0	0	0
C footprint [g/kWh]	54	434	270	72	85	53

Gas use (BAU gas)

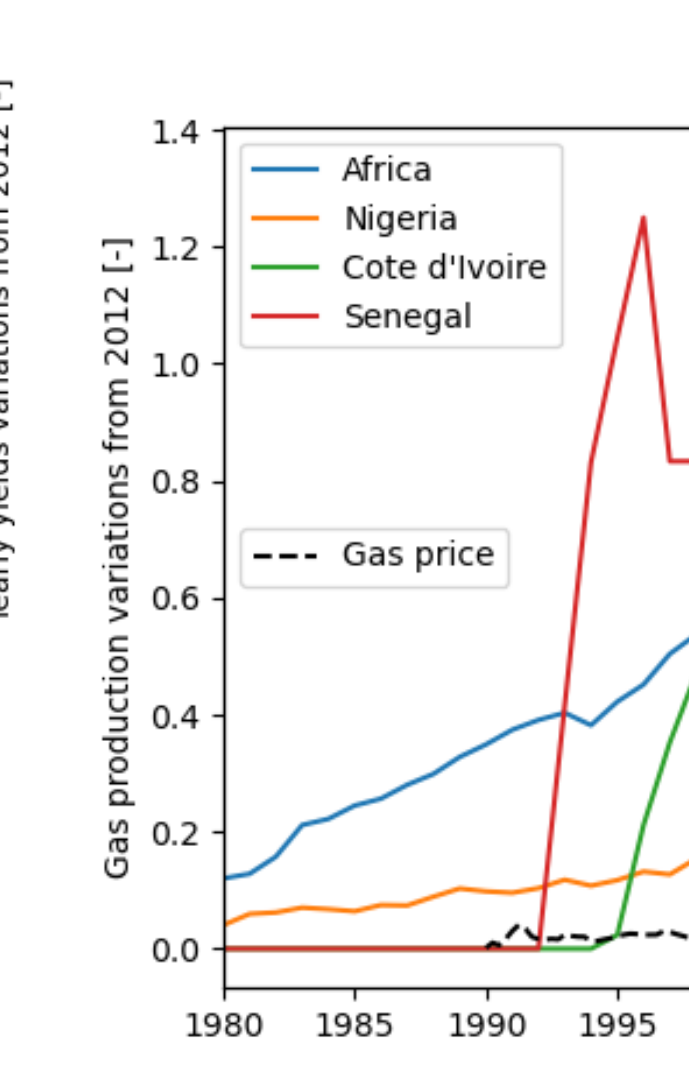
- 43 TWh, i.e. 4.5-10¹¹ m³
- ~2x yearly production
- "Baleine" <23yrs reserve

Sources:
 T. Wataai et al., Total material requirement for the global energy transition to 2050: A focus on transport and electricity. *Resources, Conservation and Recycling*, Volume 148, 2019, Pages 91-103, ISSN 0921-3449, <https://doi.org/10.1016/j.resconrec.2019.05.015>.
 S. Deetman et al., Projected material requirements for the global electricity infrastructure – generation, transmission and storage. *Resources, Conservation and Recycling*, Volume 164, 2021, 105200, ISSN 0921-3449, <https://doi.org/10.1016/j.resconrec.2020.105200>.
 I. Pappis et al., Energy projections for African countries. EUR 29904 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-12391-0, doi:10.2760/678700, JRC118432
 R. Besseau, Analyse de cycle de vie de scénarios énergétiques intégrant le contrainte d'adéquation temporelle production-consommation. Géotechnique. Université Paris sciences et lettres, 2019. <https://theses.fr/2019PSLE068>
 Champ "Baleine", Ministère des mines, du pétrole et de l'énergie. Côte d'Ivoire. <https://energie.gouv.ci/actualite/demarrage-de-la-production-du-champ-baleine>

- Availability of materials in the future ?
- Variability and uncertainties of the consumptions ?
- Interactions between sectors ? Not a real nexus approach



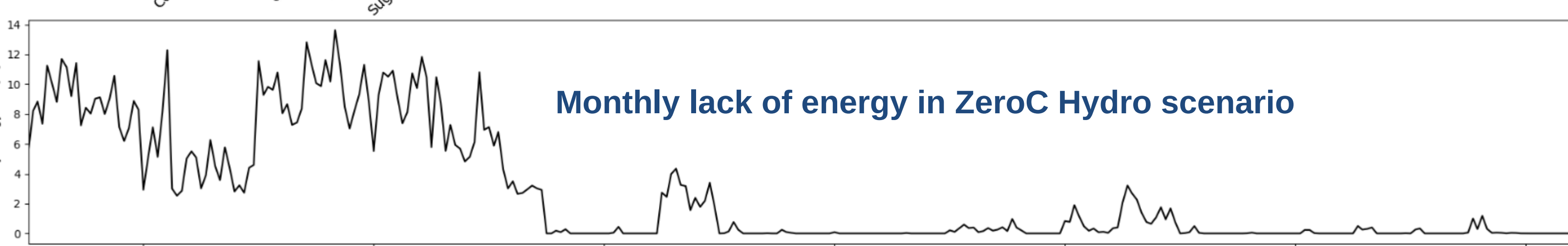
Biomass resource



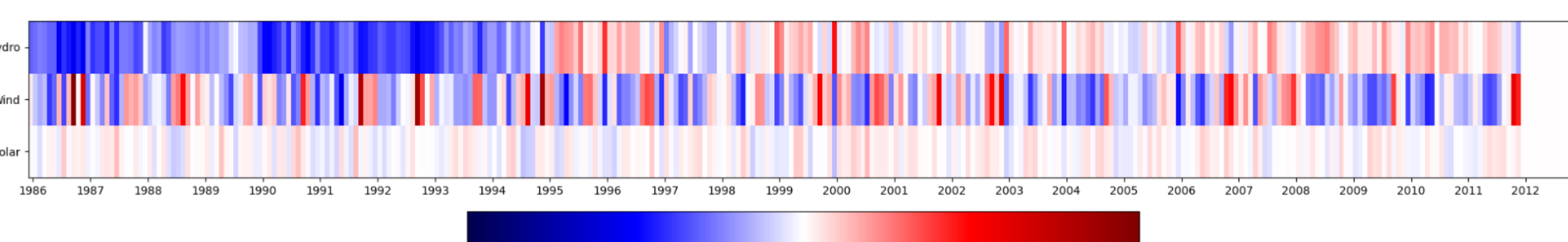
Sensitivity to resources :

- Highest impact from the interannual variability of hydro
- Gas production variable from year to another
- Large variations of agricultural yields for biomass production

- Exchanges with other countries ?
- Climate projections ?



Intermittent renewable resources (Solar, Wind, Hydro)



Sources:
 Hersbach H, Bell B, Berrisford P, et al. The ERA5 global reanalysis. *Q J R Meteorol Soc*. 2020; 146: 1999–2049. <https://doi.org/10.1002/qj.3803>
 Eklou et al., Long-term variability in hydrological droughts and floods in sub-Saharan Africa: New perspectives from a 65-year daily streamflow dataset. *Journal of Hydrology*, Volume 613, Part A, 2022, 128359, ISSN 0022-1694, <https://doi.org/10.1016/j.jhydrol.2022.128359>.
 Biomass yields, Our World in Data (consulted Oct. 2024). <https://ourworldindata.org/crop-yields>
 Gas production, Our World in Data (consulted Oct. 2024). <https://ourworldindata.org/grapher/gas-production-by-country>
 Gas price, International Monetary Fund (consulted Oct. 2024). <https://www.imf.org/en/Research/commodity-prices>

Conclusion:

- ❖ Any electricity mix has impacts, there is no "clean" mix
- ❖ Need to consider multiple incomparable criteria to design the mix
- ❖ No ideal electricity mix, but political choices

Rethink energy modeling :

- Links with other approaches
 - electrification planning
 - other energy sources/uses
- Include cross-sectoral impacts
 - use conflicts (e.g., water, land)
 - demand evolution
 - imports of energy technologies
- Consider the implementation of the mix
 - real installation capacities
 - technology diffusion
 - social behavior and lifestyles
 - impacts on populations and biodiversity