Hydrogen and electricity system planning under water scarcity constraints: Insights from France

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Overview

As the global transition toward low-carbon energy systems intensifies, Power-to-Gas (PtG) technology plays a crucial role in converting surplus electricity into hydrogen via water electrolysis. However, scaling up renewable hydrogen production presents environmental challenges, particularly concerning freshwater resources, which are expected to decline due to climate change. While the integration of water considerations has been explored in electricity systems, they have received little attention in the context of hydrogen systems.

This article examines how climate-induced water availability constraints affect joint electricity and hydrogen planning. We employ a linear programming model to optimize investment and operating decisions. A regret-minimizing approach is used to compare planning decisions with and without considering water availability constraints. We focus on a French case study at a river basin scale.

Results indicate that incorporating climate impacts on water resources leads to increased investments in renewables and PtG capacity, helping offset reductions in hydro and nuclear production and ensuring adequate hydrogen supply during summer. The regret-minimizing approach demonstrates that proactively considering the impacts of climate change on water resources in electricity and hydrogen planning minimizes regrets. This findings highlight the importance of integrating water constraints in energy system models and contribute to the broader dialogue on climate change adaptation planning.

Methods

We first develop a partial-equilibrium, linear programming model that optimizes electricity and hydrogen investment and operating decisions. The model uses an hourly resolution and aims to minimize total system costs over the year while satisfying a series of constraints. System costs include investment costs, fixed and variable operation and maintenance costs (O&M), transport costs, and Value of Lost Load (VoLL). The technology considered are described in Figure 1.

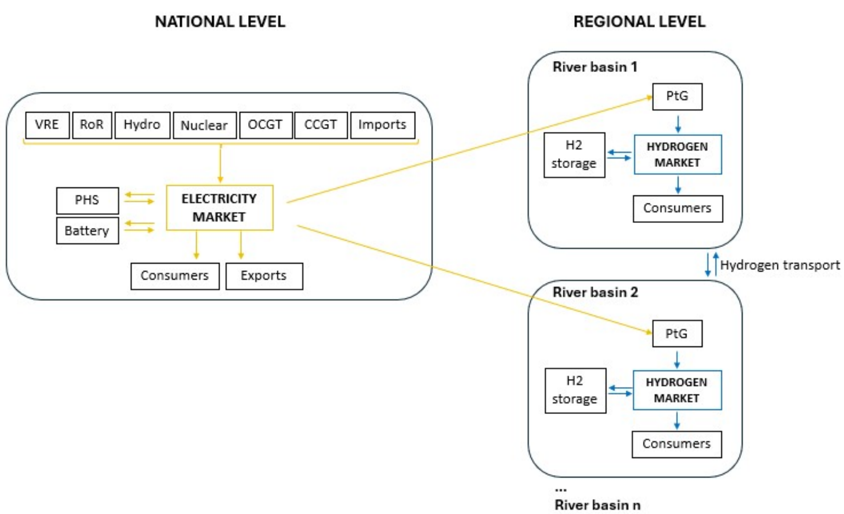

Figure 1 - Model overview

In addition to physical constraints (capacity and storage constraints) and the requirement to satisfy the supply-demand balance, our model includes a constraint concerning the availability of water resources to produce energy. This constraint requires that the quantity of water used to produce energy, plus the quantity of water needed for agriculture, drinking water and industry, be less than 40% of available water resources. Above this threshold, water consumption is generally considered unsustainable, resulting in a situation of severe water scarcity (European Environment Strategy, 2023).

We take France as a case study and focus on 2030, for which quantified targets for hydrogen development have been set (French government, 2024). As in (Khan, 2016), we account for the regional and seasonal specificities of water resources by disaggregating water and energy demands and constraints in both space and time. We conducted this study at the scale of river basins, the level at which water resources are managed in France.

Following (Khan, 2016) methodology, we divide the optimization process into two stages: the investment phase, during which the planner forecasts the investments to be made based on anticipated available water resources, and the operation phase, during which the production fleet operates given the water resources present. We consider two anticipation options during the investment phase: assuming that water resources will remain similar to historical levels or anticipating a decrease due to climate change. We study the impact of these investment choices based on the anticipation that materializes during the operational phase. Finally, we examine the relevance of including water availability constraint in the electricity and hydrogen model through a regret analysis (Chen, 2014 ; Nicolle, 2023).

Results

Our findings underline the significant impact of integrating the effects of climate change on water resources in the investment phase. Including this consideration in investment choices results in increased investment in variable renewable electricity and PtG capacity. In cases where water stress materialize, these investments mitigate the decline in exported electricity and prevent shortages in hydrogen supply during summer. Conversely, in cases where water resources are similar to historical levels, the costs associated with these investments are partially offset by increased revenues from additional exports enabled by the augmented supply. A regret analysis confirms that proactively considering climate change's impact on water resources minimizes potential regrets in decision-making processes.

Conclusions

Two key conclusions emerge from the present work. First, adapting investment decisions to a pessimistic outlook on water availability minimizes future regrets. This result is particularly relevant in the context of France's hydrogen development strategy, which does not currently consider this issue. Secondly, adapting to climate change requires, on the one hand, a shared vision of future climatic and hydrological conditions and, on the other, a clear policy regarding abstractable water volumes and hierarchy of uses. This work emphasizes the importance of accounting for water constraints in energy system models. It contributes to the broader discussion on climate change adaptation planning, which is essential to move from crisis management to structural management of water resources. Future extensions may include contrasting future scenarios and future policy decisions on water use to propose detailed adaptation strategies for the electricity and hydrogen sectors.

References

- Chen, B., Wand, J., Wang, L., He, Y., Wang, Z., 2014. Robust Optimization for Transmission Expansion Planning: Minimax Cost vs. Minimax Regret. IEEE Transactions on Power Systems 29.
- European Environment Strategy, https://www.eea.europa.eu/en/analysis/indicators/use-of-freshwater-resources-in-europe-1 (published in 2023, accessed in 2024).
- French Government, 2024. National strategy for the development of low-carbon hydrogen in France.
- Khan, Z., Linares, P., Garcia-Gonzalez, J., 2017. Integrating water and energy models for policy driven applications. A review of contemporary work and recommendations for future developments. Renewable and Sustainable Energy Reviews 67, 1123–1138
- Nicolle, A., Massol, O., 2023. Build more and regret less: Oversizing H2 and CCS pipeline systems under uncertainty. Energy Policy 179