Assessing the water footprint of hydrogen deployment in France : A Regionalized and Seasonal Approach to the Water-Energy Nexus

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Overview

The growing interest in hydrogen as a decarbonized energy vector has surged, particularly in sectors that are challenging to decarbonize, such as transportation and heavy industries. Several countries are already positioning themselves as future producers and/or exporters of hydrogen, anticipating its crucial role in the global energy transition. However, regardless of the production methods employed — whether it is through electrolysis, or natural gas reforming, biomass gasification, coal gasification, with or without carbon capture — hydrogen production is inherently water-intensive (Fairley, 2023). The energy sector already accounts for significant water consumption in every country (Moomaw, 2014), capturing approximately 55 billion cubic meters annually (IEA). As the world shifts towards a renewable and hydrogen-based energy system, there is a pressing need to evaluate its water footprint, especially in regions where water scarcity is a concern. Current debates on the water-energy nexus highlight potential global reductions in water use due to cleaner energy technologies (Calin, 2023). Several country or region-level assessments have been conducted on the impact of the energy transition on the water-energy nexus (Chen, 2017 ; Karateyev, 2019 ; Child, 2021) while others studies alerts on the sustainability of water resources as demand for hydrogen grows (Elaouzy, 2024). However, the water footprint of the transition to hydrogen is still open for investigation. Hydrogen production could exacerbate water stress in specific regions that are seeking to become hydrogen production hubs (IRENA, 2023). Some studies addressed the hydrogen-water nexus worldwide (Tonelli, 2023) and within the American context (Grubert, 2023), but they only focus on electrolytic hydrogen. When they do consider water stress indicators, they are looking at country-level and annual indicators, which tends to neglect local ans seasonal water scarcity.

Therefore, we look forward **to evaluate the water footprint of hydrogen production in 2050 in France and to compare it with local and seasonal water scarcity indicators**. The aim is to produce a methodological framework for the evaluation of the water footprint of hydrogen at a regional-level, by taking France as a study-case, and to identify potential limits on water resources. By applying a localized water-energy nexus framework to hydrogen, this study considers various water stress indicators, providing a comprehensive assessment that could be adapted to other regions. This research aligns with themes such as "energy and climate change mitigation and adaptation" and addresses "emerging modeling challenges" by integrating water resource considerations into energy modeling, while offering valuable insights for sustainable hydrogen production strategies and policy designs.

Methods

This article used seasonal water stress projection data by department in France for the year 2050, provided by DRIAS, to identify future water availability for hydrogen production. These projections allowed us to assess the spatial and temporal distribution of water resources across different regions, providing a detailed picture of potential water constraints. Hydrogen production projects were then mapped to their respective locations to correlate them with regional water stress indicators. This step enabled us to identify areas where water scarcity might pose a significant limitations to hydrogen production.

Then, we developed hydrogen deployment scenarios, using KiNESYS-IFPEN, a bottom-up, technology rich, least-cost optimization, multi-regional global integrated assessment model, which is developed using the TIMES model generator of IEA-ETSAP. The model, which integrates France as one of the modelled regions, enables to optimize the energy system subject to several constraints. We implemented several Net-Zero scenarios, testing the integration of additional water availability constraints both annual and seasonal, to simulate the impact of water scarcity on hydrogen production capacity.

Finally, the results were analyzed to (i) evaluate the overall water footprint of hydrogen production in France in Net-Zero scenarios (ii) asses the implications of local water scarcity constraints on hydrogen production. The analysis included recommendations for seasonal production adjustments, highlighting the importance of considering seasonal water availability and the potential need for hydrogen storage solutions to mitigate seasonal fluctuations in water resources. This comprehensive approach provided insights into the links between water availability and hydrogen production, offering valuable guidance for future energy planning.

Results

The study underscores the critical importance of using localized water stress indicators rather than national-level metrics when assessing the water footprint of hydrogen production. The analysis reveals that national averages can hide significant regional disparities in water availability, leading to an inaccurate understanding of the potential impacts on water resources. We also reveal that while the national average water stress indicator suggests a moderate water availability for hydrogen production, certain regions experience up to a 50% higher water stress during peak demand periods, highlighting the critical disparities masked by national averages. By focusing on departmental-level data, the study highlights regions where water scarcity could significantly constrain hydrogen production, emphasizing the need for localized assessments in energy planning. Additionally, it highlights neighboring areas that may be better suited for hydrogen production hubs than currently planned locations, though relocating production could result in increased transportation costs. Another key finding is the importance of accounting for the seasonal variability of water stress. The results demonstrate that water availability fluctuates significantly throughout the year in many regions, which has direct implications for hydrogen production. Hydrogen production in water-scarce regions fluctuates by as much as 30% between dry and wet seasons, suggesting that optimizing production schedules based on seasonal water availability will significantly reduce the overall water footprint. In areas where water resources are more abundant in certain seasons, it is essential to concentrate hydrogen production during those periods.

Additionally, the study points to the necessity of developing hydrogen storage capacities, particularly in regions where year-round production is not feasible due to seasonal water constraints. By storing hydrogen produced during periods of lower water stress, these regions can ensure a consistent supply, even when production must be scaled back due to limited water availability. This finding highlights the role of hydrogen storage in mitigating the effects of seasonal water scarcity, making it a crucial component of a sustainable hydrogen economy. These results collectively emphasize the need for a nuanced, regionally and seasonally aware approach to hydrogen production planning, ensuring that water resources are managed sustainably alongside the expansion of hydrogen as a key energy vector.

Conclusions

This article highlights the necessity of using localized and seasonal water stress indicators to accurately assess the water footprint of hydrogen production in France. The results demonstrate that relying on national-level data can mask critical regional differences, while seasonal analysis reveals the need to adjust production schedules to align with periods of higher water availability. Additionally, the development of hydrogen storage capacities is essential in regions where production is limited by seasonal water constraints, ensuring a stable hydrogen supply throughout the year. We developped a methodological framework to assess precisely the impact of hydrogen production on water resources at a regional-level.

However, the study has limitations. The projections rely on future water stress data, which may vary based on climate change scenarios and policy developments. Additionally, the model's assumptions regarding hydrogen demand and production technologies may not fully capture future technological advancements or shifts in energy policy. A more realistic assessment would require modeling hydrogen imports and considering the water footprint of these imports based on their production locations. Incorporating the water impacts of imported hydrogen would provide a more comprehensive evaluation of the total water consumption associated with France’s hydrogen consumption.

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