Assessing Uruguay's Green Hydrogen Potential: A Comprehensive Analysis of Electricity and Hydrogen Sector Optimization

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Overview

The increasing global focus on green hydrogen as an essential energy carrier reflects a widespread commitment to decarbonizing energy systems, particularly in sectors where electrification is impractical. While many leading economies have already harnessed a significant portion of their renewable energy potential, regions like Latin America possess extensive untapped renewable potentials that can be used for green hydrogen production. Uruguay, aligning with this global trend, has formulated its strategy, embodied by the "Green Hydrogen Roadmap in Uruguay"[1]. The country aims to cultivate a previously nonexistent domestic market for green hydrogen and position itself as a prominent exporter of this renewable energy resource. By 2040, Uruguay foresees a robust market for green hydrogen and its derivatives, estimating a domestic and export demand of nearly 1 million tons of hydrogen per year, necessitating the installation of 18 gigawatts of renewable energy capacity to meet the associated electricity demands.

This study and the developed model are designed to thoroughly analyze the projections outlined in the "Green Hydrogen Roadmap in Uruguay." A detailed examination of the results focuses on validation and cost calculation from both hydrogen production and electricity infrastructure perspectives. Precisely, the potential impact of different hydrogen selling prices on export opportunities is quantified. The primary objective is to evaluate the synergistic development of the electricity system and the emerging hydrogen sector. This approach generates insights into the economic and technical implications of Uruguay's green hydrogen ambitions. By showing the intricate interdependencies between hydrogen economics and energy infrastructure, a deeper understanding of the challenges and opportunities associated with transitioning to green hydrogen in Uruguay's energy landscape is aimed to be achieved.

Methods

This study employs a linear programming energy system optimization model called *urbs* [2] for multi-commodity optimization, incorporating intertemporal planning with perfect foresight. The model encompasses the existing Uruguayan electrical system alongside planned expansions, optimizing electricity generation and distribution and hydrogen production, transport, and selling.
The analysis spans multiple reference years, including 2021, 2025, 2030, 2040, and 2050, providing a comprehensive outlook on the evolution of Uruguay's energy landscape.
Specifically, this research aims to forecast the potential hydrogen production under varying selling prices, enabling the optimization of electrolyzer installation, hydrogen production, and electricity system expansion. The optimization process prioritizes the export of hydrogen based on the profitability of selling prices; if the conditions indicate profitability, the model selects to export hydrogen; otherwise, no hydrogen export is chosen.
To assess renewable energy potential and incorporate temporal dynamics, we utilize the pyGRETA tool [3], facilitating accurate calculations and time-series analyses. The modeling framework *urbs* encompasses the entire electricity sector, integrating diverse technologies essential for hydrogen production and storage. For a detailed illustration of the modeled system and its components, please refer to the provided reference energy system in Figure 1.

Results

The results show notable expansion within the electricity sector, driven by the increased demand necessitated by hydrogen production. The study thoroughly evaluates the quantities of hydrogen sold and their corresponding marginal costs, considering diverse price points for H_2 and its derivatives. Furthermore, an analysis is conducted to assess the realized potential of hydrogen production under current market conditions. The longitudinal examination reveals the evolving trajectories of both sectors across the reference years, offering insights into their developmental patterns. Moreover, the study delineates the decarbonization pathways for the established electricity sector and the growing hydrogen industry, revealing their respective roles in Uruguay's journey toward sustainable energy transition.

Conclusions

Upon closer examination of the preliminary results, it becomes evident that the cost of hydrogen escalates notably when factoring in integration costs and the temporal availability of renewable resources. It is imperative to comprehensively analyze Uruguay's intrinsic electricity demand alongside hydrogen perspectives. Solely focusing on hydrogen production overlooks the nuanced dynamics of future energy provision, potentially leading to the exploitation of only the most cost-effective energy sources and optimal sites. However, as energy demands grow, the necessity arises to tap into progressively less favorable sites with higher relative costs. Additionally, with the projected increase in the country's electricity demand, accommodating additional capacity solely for hydrogen production becomes financially burdensome in the future. It could be financially viable for pilot projects to start producing green hydrogen as early as 2025.

This underscores the importance of strategic planning and timely implementation to efficiently navigate Uruguay's evolving energy landscape.

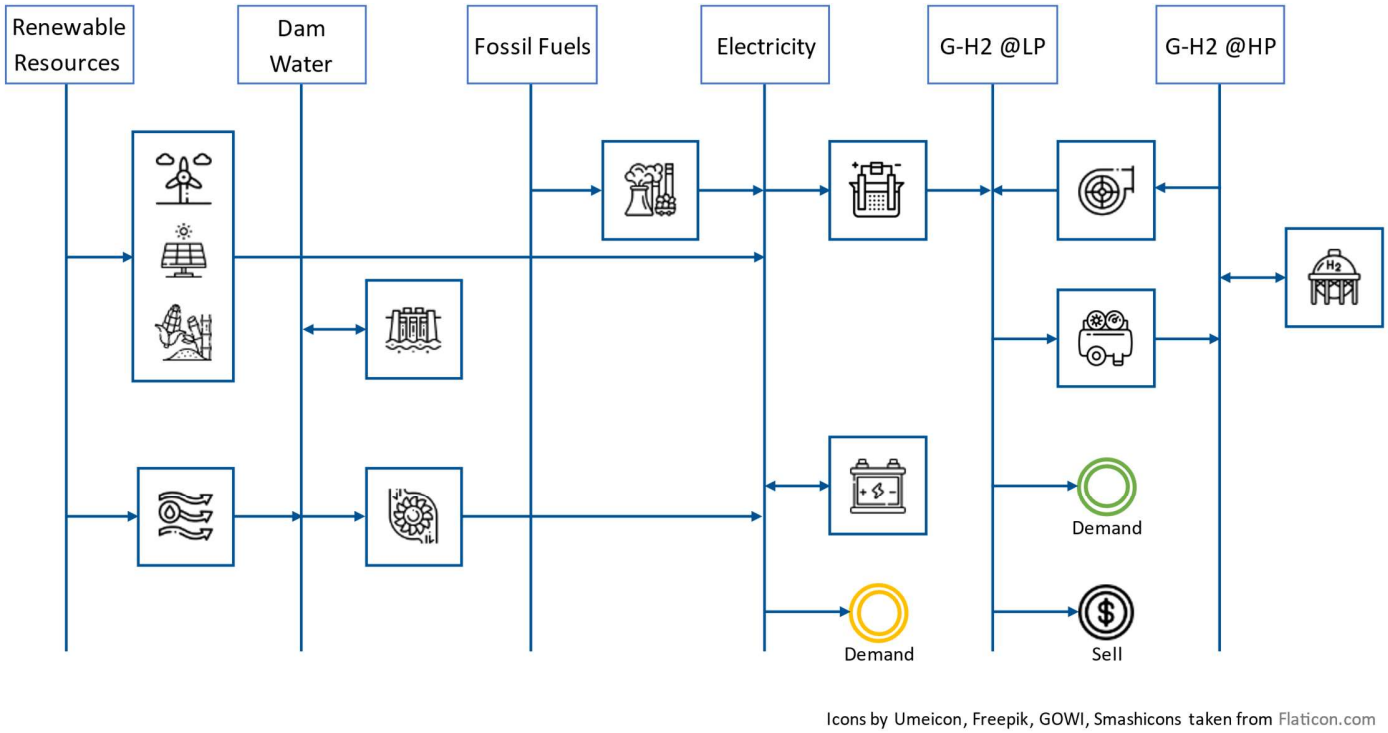

Figure 1 Reference energy system for the Uruguayan Electricity System and Hydrogen Production. G-H2: Gaseous Hydrogen. LP: Low pressure. HP: High pressure.

References

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