Technical Session 5B (15:20 - 16:30)	**Hydroplant under New Energy Mix and Environmental Constraints**	**Chair: Gabriel Cunha, PSR**	
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Impact of environmental constraints in hydrothermal energy planning

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1. Objective

The primary objective of this study is to assess the impact of Environmental Constraints (ECs) on Long-Term Generation Scheduling (LTGS) problems with high penetration of hydrothermal generation, focused on the Brazilian power system. Given the increasing importance of environmental regulations in energy planning, this research aims to evaluate how prioritizing multiple water uses —such as human consumption, navigation, and ecological preservation— affects hydroelectric generation and overall system operation. Furthermore, the study seeks to compare different mathematical formulations for modeling these constraints, analyzing their effects on energy dispatch, water values, and operational costs. Finally, we investigate the computational complexity associated with these formulations, aiming practical applicability for large-scale LTGS problems.

2. Methodology

This study formulates the LTGS problem as a multi-stage stochastic mixed-integer linear programming model, solved via Stochastic Dual Dynamic Integer Programming. The ECs are incorporated using two distinct modeling approaches, each with different implications for computational efficiency and solution accuracy:

- Binary-based approach: this method introduces 0-1 decision variables to classify reservoir operation into distinct modes —normal, restricted, and attention— based on storage levels. While this approach provides an explicit representation of regulatory constraints, it increases model complexity due to the presence of integer variables.

- Piecewise Linear (PWL) approximation: Instead of discrete classifications, this approach employs concave PWL functions to approximate ECs continuously. This formulation seeks to balance model tractability and accuracy by avoiding integer decision variables while still capturing key operational limitations.

To evaluate the effectiveness of these approaches, numerical simulations are conducted on a subset of the Brazilian hydrothermal system, comparing the results against Newave, Brazil's official long-term energy planning model. The assessment includes:

- The impact of ECs on system operation and cost.
- A sensitivity analysis on different demand levels and penalty costs applied to constraint violations.
- A computational performance evaluation, measuring solution times and iteration convergence behavior for both modeling approaches.

3. Preliminary Results

The preliminary outcomes of this study include both theoretical and practical understanding into the impact of ECs on hydrothermal LTGS problem. Specifically, we anticipate the following results:

- Operational and Economic Impact: a quantitative assessment of how ECs influence hydroelectric dispatch, reservoir storage policies, and system-wide energy costs. The study aims to determine whether stricter constraints lead to increased reliance on thermal generation and higher marginal operation costs.
- Water Valuation Analysis: a comparison of future cost functions under different formulations, evaluating how ECs alter the opportunity cost of water in long-term planning.
- Comparative Assessment of Formulations: a study contrasting the binary-based approach and the PWL approximation in terms of solution accuracy, computational performance, and practical applicability.
- Computational Complexity and Scalability: an evaluation of the computational effort required by each formulation, including convergence behavior, solution time, and the scalability of the models when applied to LTGS problem.

The obtained results suggest that stricter environmental regulations increase system costs by limiting hydro dispatch flexibility, leading to greater reliance on thermal generation. Additionally, the study is expected to demonstrate that while binary-based formulations offer almost precise constraint representation, they impose higher computational costs, whereas PWL approximations may provide a more efficient yet sufficiently accurate alternative.

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Impacts of a green hydrogen industry in the Brazilian energy matrix

(1) objective (2) methodology (3) (expected) results.

Green hydrogen (H2V) is gaining prominence around the world as a viable solution to address climate challenges and promote a more sustainable future. Produced from renewable energy sources, it is recognized as a key element in meeting greenhouse gas emission reduction targets, specifically the Paris agreement, which requires 60% of carbon dioxide emissions to be cut by 2050.

World hydrogen consumption in 2022 was 95 million tons, representing an increase of 3% compared to the previous year. However, most of today's hydrogen production is done by processes that use natural gas as a feedstock, and focus on specific applications such as oil refining and ammonia production. However, the technological and industrial evolution of electrolyzers as well as the reduction of the production costs of renewable energies has led H2V to several applications such as transportation, heating and industry, especially steel and fertilizers, even though its share is still small (0.6% of the total demand). The global outlook for green hydrogen by 2030 is optimistic, with demand expected to exceed 200 million tons [1].

Brazil is among the most competitive countries for the production of green hydrogen. According to studies, the levelized cost of Brazilian green hydrogen would be around US$ 1.50 per kilogram of H2 in 2030. This puts it in line with the best locations in the US, Australia, Spain, and Saudi Arabia, and could reach around $1.25 per kilogram of H2 by 2040 [2]. Competitive costs should attract investments for national green hydrogen production, benefiting from the existing electricity grid and the high availability of renewable resources for electricity production, responsible for 70% of the hydrogen production cost.

Aware of the opportunities for the country and already envisioning international cooperation, the Management Council of the National Hydrogen Program (Coges-PNH2) was created in 2022, composed of different ministries and institutions to enable the development of the hydrogen market and industry as an energy vector in Brazil. This council approved in 2023 a three-year plan (2023-2025) of the National Hydrogen Program (PNH2) [3] that defines routes and goals focused on the production of low-carbon hydrogen.

In view of this perspective, for this article a study on electro-energetic planning and operation of the Brazilian System (SIN) was prepared for a scenario with the implementation of an industry for the production of green hydrogen in Brazil. From case studies of the Ten-Year Expansion Plan (PDE) of the Energy Research Company (EPE), using the official planning models, it was possible to demonstrate that, even in a conservative scenario where only 60% of the Brazilian potential of 9 million tons by 2040 [2] would be explored, the increase in the electricity demand caused by the new hydrogen industry would be able to absorb all renewable projects already granted by ANEEL, over 100GW of installed capacity, as can be observed in Fig.1. Such a scenario would cause a major impact on the Brazilian energy matrix and would require expansion not only of renewable generation sources to meet such demand, but also of the system's infrastructure, in addition to demanding solutions to ensure the safety and operational reliability of the national interconnected system.

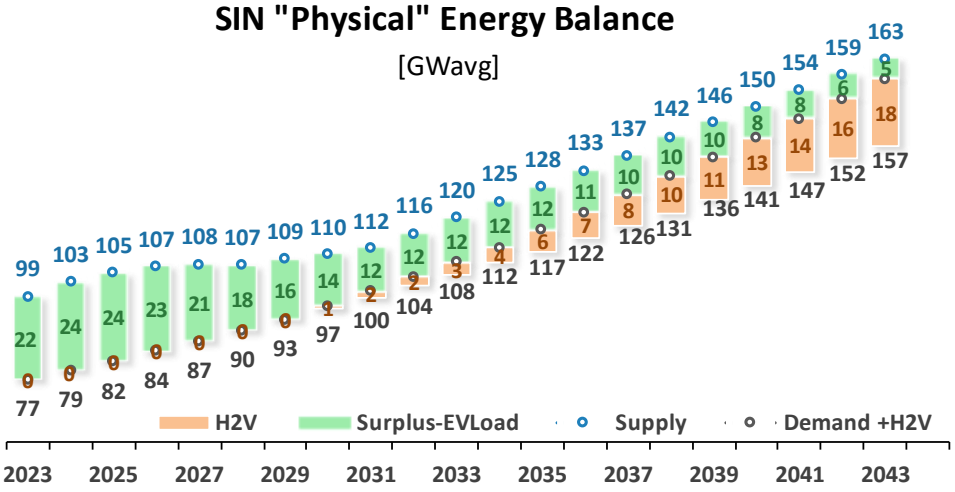

Fig. 1 – Energy balance with a H2V industry

In the proposed article, potential changes in the energy matrix and in the balance of supply and demand, incurred by the insertion of a H2V industry will be presented and analyzed in terms of operation indicators such as cost, water storage, hydroelectric generation factor (GSF) and power supply capacity.

The potential of H2V in the decarbonization of the economy and energy transition to a more sustainable future is very expressive, and planning studies such as the one proposed in this article are essential to define an action plan and the economic viability of the solutions.

Keywords: Energy matrix; energy transition; green hydrogen; H2V; operation planning; expansion planning; PLD; GSF.

References

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From PPAs to Wind Firming: Evaluating New Hydropower Capacity in Iceland

Planning hydropower expansions to serve both new firm load and intermittent wind resources presents an interesting scheduling challenge. This study presents a two-step method for assessing the optimal size of a new or expanded hydropower plant. First, a coarse-resolution scheduling simulation determines *generation adequacy* by evaluating how much extra firm load can be supported at the same production cost as a baseline. Next, a high-resolution scheduling step incorporates wind variability, measuring how well additional hydropower capacity can firm intermittent output. The result is a pair of curves—one reflecting firm load coverage and the other showing wind firming potential—that, when tied to projected revenue streams (e.g., long-term PPAs and wind-firming contracts), reveal the most profitable capacity point. Demonstrated using real-world data from the Icelandic power system, the approach illustrates how hydropower scheduling can be leveraged to justify expansions beyond simple energy adequacy considerations, ensuring both higher system reliability and added revenue from firming services