Estimates of green hydrogen production potential in Brazil using system dynamics

Mauricio Uriona Maldonado, Universidade Federal de Santa Catarina, m.uriona@ufsc.br

Caroline Rodrigues Vaz, Universidade Federal de Santa Catarina, caroline.vaz@ufsc.br

# Introduction

Green hydrogen (GH2) is recognized as a crucial player in combatting climate change, positioned strategically to enhance energy security, revamp existing energy structures, and invigorate various industrial sectors. Its role in industrial decarbonization aligns with the imperative for a more efficient utilization of renewable energy sources (Capurso et al. 2022). GH2 introduces novel prospects across industrial, transportation, and hybrid applications (Chantre et al. 2022), but the critical concern of production costs necessitates national strategies to support the entire GH2 value chain.

Brazil, with its clean electricity matrices largely sourced from renewables, emerges as a potential global leader in GH2 production (EPE - Empresa 2023) and exports to European markets, especially Germany. The nation's achievement in clean energy stems from a two-decade-long collaborative effort between public and private sectors. Simultaneously, Brazil's National Hydrogen Program and Germany's updated National Hydrogen Strategy indicate parallel trajectories, with Brazil aspiring to lead in GH2 production, and Germany positioning itself as a technology supplier and GH2 importer.

However, the potential collaboration between Brazil and Germany faces challenges. First, the need to measure the potential of GH2 production Brazil will have in the coming years, and second to estimate the required energy demand the country will have to meet, in order to produce electrolizer-based GH2. In this line, the main objective of this paper is:

To develop green hydrogen production scenarios in Brazil for the upcoming decades.

**Method**

To achieve the objective, we will utilize system dynamics, which is a simulation modeling approach that is based on causal feedback dynamics, accumulations and delays. System dynamics models are equation-based and use time as continuous (Naugle, Langarudi, and Clancy 2023).

The system dynamics model employed in this study draws inspiration from the Bass diffusion theory, a framework that elucidates the adoption process of new products within a population. Originally proposed by Bass in 1969, this model provides insights into how both existing and potential adopters interact, offering a pioneering perspective on the role of internal and external communication in introducing innovations to the market (Peres et al., 2010; Sterman, 2000).

The Bass model is rooted in the value-added behavior of a product, denoted by its sales potential "m," diffused within a socially homogeneous and concentrated system. In this framework, consumers experience external influence "p" (marketing) and internal influence "q" (word of mouth) continuously over time "t" due to interactions within the social system. Bass's key conclusion asserts a linear relationship between adoption probabilities and the original quantity of potential buyers. This foundational principle has been extensively scrutinized and validated across various consumer goods, demonstrating the model's capacity to replicate observed behaviors in real-world situations (Bass, 1969).

The mathematical equation that synthesizes Bass  model can be written as:

P(t)=p+q\*(S + (t)m)

Where P(t) represents the probability of purchase at time t and S(t) represents the total, at time t, of consumers who have already purchased the product. The coefficients "p" and "q" are known respectively as the "innovation coefficient" and the "social contagion coefficient". It can be seen that there will be a growth of P(t) as the proportion of consumers "(S + (t)m)" increases and this will occur proportionally to "q".

To construct the scenarios and address the associated equations, we will employ Stella Architect by Isee Systems.

# Results

The production of hydrogen (GH2) exhibits an exponential growth trend owing to technological advancements. The baseline scenario indicates an H2 production of 3 to 10 million tons per year, by 2040, aligning with ongoing projects in the country, the largest being 0.9 tons/year from an Australian company. The capacity of H2 in Ammonia follows a stepwise increase, synchronized with the actual H2 production. Initially, this capacity progresses slowly due to the presumed high energy consumption, hindering H2 production. Over time, additional large ammonia plants may integrate the system as H2 and renewable energy (RE) experience more predictable growth. This progression introduces the possibility of an overshoot in the fourth step, leading to excess capacity.

On the other hand, electrolizer installed capacity might reach between 30 and 90GW by 2040, indicating the need to significantly increase overall renewable installed capacity in the country.

National consumption remains marginal as a percentage of total production, with an estimated size of 0.7 to 3 million Tons per year by 2040, and the European Union’s consumption reaching between 4 and 41 million Tons per year by 2040.

**Conclusions**

Although the precise costs and economic feasibility for the domestic market require further clarification, this study emphasizes the importance of enacting policies for meeting electrolizer demand, securing domestic consumption of GH2 and increasing GH2 exports to Europe, especially Germany.

Such policies are essential to safeguard its low-carbon advantage. The presence of domestic industries capable of utilizing GH2 is crucial for optimizing the country's potential. Moreover, policies should promote local value creation, opening avenues for Brazilian enterprises to engage in the burgeoning GH2 supply chain and contribute to its growth.

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