ASSESSING THE IMPACT OF HYDROGEN INDUSTRY DEVELOPMENT ON MINERAL SECURITY IN SAUDI ARABIA USING SYSTEM DYNAMICS MODELS

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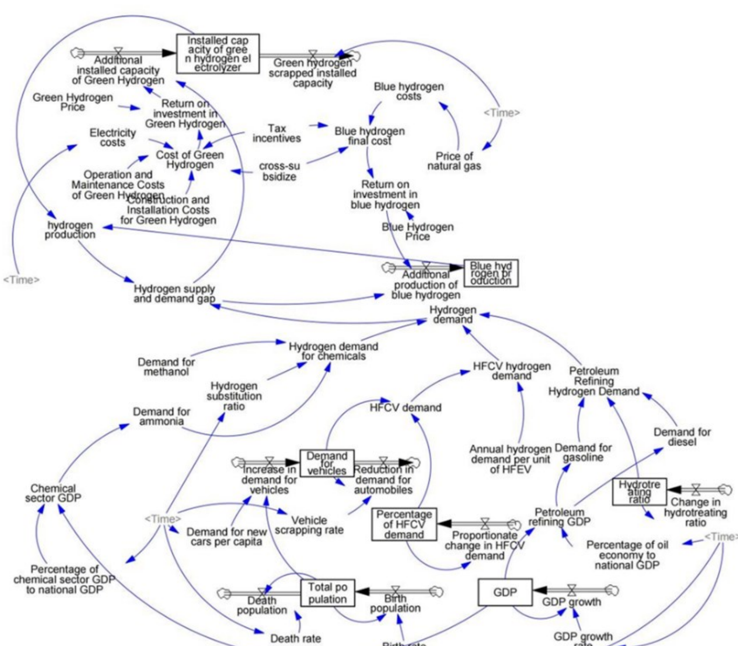
Overview

Saudi Arabia has significant potential to develop a robust hydrogen industry, leveraging its abundant natural resources, strategic location, and ambitious national vision. The Kingdom plans to produce low-cost green hydrogen while utilizing its well-established oil and gas infrastructure for blue hydrogen. The demand for hydrogen as a feedstock in chemical production, particularly for ammonia and methanol, as a fuel for fuel cell vehicles, and as a key additive in petroleum refining, is expected to grow substantially in the coming decades. Additionally, hydrogen has the potential to decarbonize energy-intensive industrial processes, such as iron and steel production (H2-diplo. 2023). However, the development of the hydrogen industry faces challenges. The high initial costs of hydrogen production technologies, coupled with the need for infrastructure development for storage, transport, and distribution, present economic barriers. Materials such as nickel, zirconium, platinum, iridium, lanthanum, and yttrium—none of which are currently produced domestically—are crucial for hydrogen production. This raises questions about whether Saudi Arabia's ambitions for hydrogen development are achievable given internal and external constraints, and how hydrogen energy development will impact the supply-demand dynamics for mineral resources within the Kingdom.

Methods

To answer the research questions, this paper constructed system dynamic models (SDM) to simulate the development of hydrogen industry development in Saudi Arabia and evaluate the supply and demand of key resources needed for hydrogen production. Main factors that are considered in the module for hydrogen industry development include demographic changes, profit changes, policy changes, technological changes, and supply-demand changes (Figure 1). In addition to natural gas-based steam methane reforming (SMR) production for blue hydrogen, this paper also examines minerals supply and demand for three mainstream electrolyzer technologies for green hydrogen, including alkaline electrolytic cells, proton exchange membrane (PEM) electrolytic cells, and solid oxide electrolytic cells (SOEC).
Figure 1. Stock and flow chart forecasting the development of hydrogen industry



The models are developed using Vensim PLE software, with all modules running from 2010 to 2050 and a simulation step of one year. Data from 2010 to 2020 are used for model construction and validation. As Saudi Arabia's first green hydrogen project is expected to become operational in 2025, the model uses 2025 as the starting point for estimating green hydrogen production.

- For green hydrogen production, the service life of an electrolyzer is 20 years, meaning the scrapping and recycling of electrolyzer equipment can occur within the study's time frame. The installed capacity of electrolyzers is used as a state variable to represent the progress of green hydrogen development. Meanwhile, the newly installed capacity and the decommissioned capacity of electrolyzers are considered rate variables, directly influencing the total installed capacity of electrolyzers over time.
- For blue hydrogen, the lifespan of hydrogen production equipment exceeds 60 years, meaning the decommissioning and recycling of such equipment are unlikely to occur within the study's timeframe. Blue hydrogen production serves as a state variable to indicate the status of its development, while newly installed capacity is treated as a rate variable that directly impacts production levels.

Results

This research considers two policy scenarios and one technology scenario. The baseline scenario represents current policy target and an ambitious scenario with higher policy targets, where the hydrogen substitution ratios for chemical products, fuel cell vehicles, and petroleum refining hydrotreating are doubled compared to the baseline scenario. The technology scenario focuses on material recycling.

- For alkaline electrolyzers, Saudi Arabia's aluminum resources can meet the demands of hydrogen energy development, but significant supply and demand gaps exist for nickel and zirconium. Under the baseline policy scenario, by 2045, the supply-demand gap for nickel and zirconium is projected to peak at approximately 1,022,820 kg and 102,282 kg, respectively. Recycling and secondary utilization of scrapped electrolyzers can mitigate 16.14%–38.63% of this gap. Under the ambitious policy scenario, by 2045, the supply-demand gap for nickel and zirconium increases to approximately 2,002,060 kg and 200,206 kg, respectively. Recycling efforts in this scenario can cover 19.66%–54.80% of the supply-demand gap.
- For PEM electrolyzers, Saudi Arabia faces a long-term supply-demand gap for platinum and iridium, posing substantial supply risks. In the baseline policy scenario, by 2045, the supply-demand gap for platinum and iridium is expected to peak at approximately 307 kg and 716 kg, respectively. Recycling of scrapped electrolyzers can address 21.52%–51.51% of this gap. In the ambitious policy scenario, by 2040, the supply-demand gap increases to 573 kg for platinum and 1,337 kg for iridium, with recycling efforts potentially covering 26.21%–73.07% of the gap.
- For SOECs, Saudi Arabia will face significant supply-demand gaps for nickel, zirconium, lanthanum, and yttrium, creating critical supply risks. Under the baseline policy scenario, by 2045, peak supply-demand gaps are expected to reach approximately 178.99 tons for nickel, 40.91 tons for zirconium, 20.46 tons for lanthanum, and 5.11 tons for yttrium. Recycling and secondary utilization of scrapped electrolyzers could address 8.07%–38.63% of this gap. In the ambitious policy scenario, by 2045, peak supply-demand gaps increase to 350.36 tons for nickel, 80.28 tons for zirconium, 40.04 tons for lanthanum, and 10.01 tons for yttrium. Recycling efforts in this scenario can mitigate 13.37%–54.80% of the supply-demand gap.

Conclusions

The development of the hydrogen industry faces several challenges. Technological advancements, particularly in electrolyzer efficiency, hydrogen storage, and fuel cell technologies, are essential to improving competitiveness and scaling production. Most critical minerals that are needed for electrolyzers technologies are not produced locally, which impose geopolitical and market risks on minerals supply chain. Addressing these challenges requires strategic investments in mineral recycling, international partnerships for resource acquisition, and technology innovation to reduce dependency on scarce materials. This paper examines the meaningful contribution of recycling and secondary utilization of scrapped electrolyzers to mitigate long-term minerals resources challenges in Saudi Arabia.

Reference

H2-diplo. 2023. "Saudi Arabia's Potential to Enhance its Position as a Key Goods' Provider for the Energy Transition and the Upcoming Hydrogen Economy." https://h2diplo.de/wp-content/uploads/2024/07/Study-H2-industry-KSA_2024_final-1-1.pdf