The Role of Hydrogen-Ready Gas Power Plants in Germany's Energy Transition

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Overview

As Germany transitions towards a decarbonized energy system, the integration of hydrogen technologies has been hailed as a game-changer. Most recently, the federal government in Germany published a power plants strategy aiming to support H2-Ready gas-fired power plants, that will initially run with natural gas, and latest by 2040 shift to run on green hydrogen. This study explores the role of H2-Ready power plants in transitioning toward a decarbonized energy system and plausible pathways using a capacity expansion model. The preliminary results show that H2-Ready power plants drastically reduce over-investments in renewables and flexibility measures, improve renewables utilization, and offer unmatched flexibility for the system.

Methods

Using an open-source capacity expansion model, MyPyPSA-Ger, this study develops pathways for hydrogen integration within Germany's power sector. Through a scenario-based analysis, the study assesses the economic feasibility and flexibility implications of H2-ready gas-fired power plants, exploring how these plants could support a renewables-dominated power system. This approach allows for a rigorous comparison of support mechanisms, such as CAPEX and OPEX subsidies, local versus imported hydrogen production, and carbon pricing, to evaluate which policy interventions most effectively balance environmental and economic sustainability. To provide policy-relevant results, we develop and compare eight different scenario variants as shown in Table 1.

Table 1: Summary of scenarios settings

Scenario	H2-Imports	H2-Ready Capability	H2-Ready Shift	H2-Subsidy	EU ETS Price
BAU	x	x	x	x	75 €/ tCO_2
Imports	✓	x	x	x	75 €/ tCO_2
H2-Ready	✓	✓	From 2040	x	75 €/ tCO_2
H2-Ready-Plus	✓	✓	From 2040	30 GW	75 €/ tCO_2
H2-Ready-OPEX	✓	✓	From 2040	1 €/kgH_2 used in CCGT	75 €/ tCO_2
H2-Local-1.0	✓	✓	From 2040	1 €/kgH_2 domestically prooduced	75 €/ tCO_2
H2-Ready-CO2	✓	✓	From 2040	x	Annual linear development: 113 €/tCO2 by 2030 179 €/tCO2 by 2040 218 €/tCO2 by2050
H2-Ready-2035	✓	✓	From 2035	x	75 €/ tCO_2

Results

Our analysis reveals a clear dominance of solar and onshore wind within the future German power system, even in scenarios that incorporate hydrogen-ready gas-fired power plants. Notably, the absence of flexibility provided from thermal power plants – specifically H2-Ready capabilities – in the *BAU* and *Imports* scenarios results in a significant increase in installation rates. The introduction of hydrogen-ready capabilities in gas-fired power plants substantially alters the energy landscape. The inclusion of H2-Ready capabilities alleviates the investment pressures associated with other flexibility solutions, such as battery storage or hydrogen fuel cells, while simultaneously reducing investments in solar and wind technologies.

Overall, the different pathways developed in this study present various results in terms of flexibility portfolios, with different impacts on transformation costs and cumulative system emissions. Additionally, the inclusion of various flexibility measures results in a considerable increase in peak demand, which is necessary to meet the system's growing requirements. In scenarios lacking H2-Ready capabilities, peak load nearly triples by 2050, while scenarios featuring H2-Ready capabilities see peak loads more than double by 2050, increasing further with hydrogen subsidies. Without H2-Ready CCGT or hydrogen imports, the system achieves flexibility largely through substantial amounts of battery storage, fuel cells, and imbalances from expensive ramp-up generators. Enabling hydrogen imports into the system reshapes the flexibility portfolio by reducing fuel cell requirements by around 7 GW and cutting imbalances by more than half, while slightly rising battery flexibility needs. Scenarios with H2-Ready capability hugely alter the flexibility portfolio, reducing battery requirements by at least 65%, completely eliminating imbalances, and cutting fuel cell needs by at least 10 GW. Gas-based flexibility also decreases in scenarios with H2-Ready capabilities.

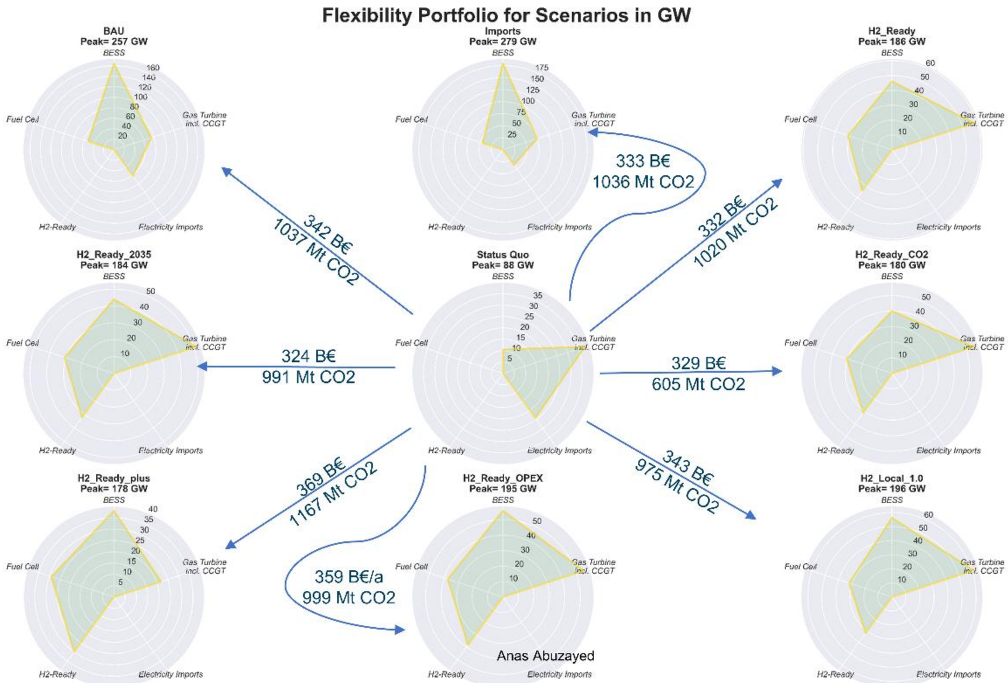

Figure 1: Flexibility portfolios for all scenarios

CAPEX subsidies for H2-Ready power plants result in the lowest flexibility requirements compared to other H2-Ready scenarios. However, this scenario also raises CO_2 emissions and total system costs substantially. In contrast, all other scenarios with H2-Ready capability cut cumulative CO2 emissions by at least 17 million tonnes and generally reduce transformation costs. Subsidies on hydrogen usage and production achieve emission reductions, while raising the system costs. Policy interventions without support schemes emerge as the most effective strategies for reducing both costs and emissions. For instance, an earlier mandatory shift to hydrogen in H2-Ready power plants reduces emissions, while having the cheapest system transformation costs. Likewise, higher CO2 prices decrease costs and achieves a substantial CO2 emissions reduction.

Conclusions

The preceding analysis evaluates the integration of the H2-Ready CCGT power plants in Germany to assess their role in advancing the energy transition. Due to their enhanced ability in providing flexibility, H2-Ready CCGT power plants play a significant role in reducing the over-investments in renewable technologies and additional flexibility measures. In conclusion, while all scenarios lead to a carbon neutral power system by 2045, the role of H2-ready technologies ensuring system flexibility and reducing emissions is clear. The strategic deployment of hydrogen in conjunction with renewables, along with targeted policy measures, significantly influences the transition pathways and ensures the system can manage periods of low renewable output without excessive cost or resource overbuild. This study shows that balancing approaches to policy design will be key to achieving a cost-efficient decarbonized power system in Germany.

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