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Quantifying the additionality of grid-connected hydrogen in a decarbonising energy system

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Green hydrogen is widely seen as essential for decarbonising our energy system. However, the additionality of grid-connected green hydrogen production prevents it from being cost-efficient and clean. The additionality of grid-connected hydrogen production is the cost and carbon intensity from additional thermal generation compared to the case when no hydrogen is produced. This research quantifies this additionality by defining a fair cost and carbon intensity of grid-connected hydrogen production. Using a two-layer model of Great Britain's power system, both today and in a future with high Variable Renewable Energy (VRE) penetration, we compare three electricity consumption strategies: 1) using curtailment, 2) using VRE generation before the wholesale electricity market (VRE-ahead), and 3) using grid electricity (on-grid). We found that in the current GB power system, VRE-ahead is the best choice, but using curtailment will be more preferable if the annually levelized cost of electrolyser is lower than 11 pounds/KW/year, and using curtailment will always be the cleanest method. In the future GB power system, when all planned capacity is installed, using curtailment will be the most cost-efficient strategy and it will produce enough hydrogen to replace current grey hydrogen use in the UK.

A dedicated wind-hydrogen project using the wind profile of Edinburgh is modelled, and it reveals that the lifecycle cost of hydrogen production from dedicated wind has already competitive currently. A transfer cost list from green hydrogen to mainstream hydrocarbon liquid fuel and natural gas is also made to signify the competitiveness of green hydrogen.

We also find a decarbonization paradox: Offsetting the additional emissions from hydrogen production becomes much harder as the power grid gets cleaner. In a future decarbonised system, the amount of new VRE capacity required to cancel out hydrogen additionality is substantially higher than in today's grid, even though the scale of additionality is less. This presents a significant and underestimated challenge for achieving net-zero goals without proper additionality regulations in the power system.

This research reveals the potential of using curtailment to produce green hydrogen in a highly VRE penetrated power system and signifies the importance of hydrogen additionality regulation. Policymakers may find lessons on incentive green hydrogen production from this, and green hydrogen investor will gain insights for their electricity consumption strategy.

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