

Stand-alone Power-to-X Production Dynamics - A Multi-Method Approach to Quantify the Emission-Cost Reduction Trade-off

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Abstract

Power-to-X processes allow for increased utilization of renewable energy in sectors like transportation, heat, and industry, where greenhouse gas emissions are hard to abate or irreducible. However, due to significantly higher production costs than conventional alternatives and the requirement of lower greenhouse gas footprints, Power-to-X processes must aim for low-cost and low-emission production. This work introduces a multi-method approach by combining process simulation, techno-economic analysis, life cycle assessment, renewable electricity generation modeling, and multi-objective optimization to investigate the relationship between Power-to-X production costs and greenhouse gas emissions to support investment decisions. The approach is applied to produce renewable hydrogen, Fischer-Tropsch crude, and methanol by considering global weather data with hourly temporal resolution. Our results show that locations with high wind capacity factors achieve the lowest costs and greenhouse gas emissions, and locations with high solar PV capacity factors perform worst in the context of greenhouse gas emissions when producing Power-to-X products, primarily due to the emission-intensive production of solar PV modules. Locations with mixed capacity factors of wind and solar PV allow cost-efficient greenhouse gas emissions reduction since solar PV capacities can be substituted with a combination of wind generation capacities and battery storage. In addition, flexible Power-to-X technologies reduce costs and greenhouse gas emissions significantly since fewer auxiliary components like storage units are needed.