Long-Term Infrastructure Planning: A North Sea case study on Hydrogen and CO_2 Pipeline Networks

Veronika Lenivova, Fraunhofer IEG and TU Dresden, veronika.lenivova@ieg.fraunhofer.de
Natalia Pieton, Fraunhofer IEG and KIT, natalia.pieton@ieg.fraunhofer.de
Christoph Nolden, Fraunhofer IEG, christoph.nolden@ieg.fraunhofer.de

Overview

The energy transition in the European Union (EU) is advancing rapidly, with the North Sea region emerging as a focus area due to its unique geographical and economic characteristics. This region includes several heavily industrialised countries such as Germany, the Netherlands and the UK, where the demand for hydrogen and synthetic fuels is expected to be the highest in the EU. On the other hand, due to the high offshore wind potential in the North Sea, especially in the offshore zone of Denmark and Norway, this area could become the new hub of electricity and hydrogen production in Europe. In addition, the region has a dense oil and gas pipeline infrastructure and established supply agreements between countries. These characteristics raise critical questions about the restructuring of established supply chains and the potential repurpose of this infrastructure and the development of new networks in the context of the energy transition.

This study aims to enhance understanding of strategic infrastructure development in the North Sea region by investigating the optimal investment decisions to achieve economic efficiency and climate neutrality. Key objectives include determining the hot spots necessary scale and policy adjustments for transport infrastructures. However, several infrastructure challenges are to be overcome to achieve energy transition. These include the different levels of acceptance of carbon capture, transportation, and storage technologies (CCS/CCU) across North Sea countries, which restrict significantly infrastructure planning.

Existing studies highlight the advantages of integrating hydrogen (H_2) and carbon dioxide (CO_2) pipelines into energy system models, demonstrating substantial total cost savings compared to a system where such infrastructure is not included (Hofmann et al., 2024). By adding H_2 and CO_2 infrastructure in system models, it becomes possible to unlock cost-optimal locations for renewable hydrogen production and access low-cost sustainable carbon sources for synthetic fuel production. However, significant uncertainties remain, particularly regarding the demand quantities, locations and economic feasibility for hydrogen and synthetic fuels production. Addressing these uncertainties is critical to ensure security of supply across sectors while meeting diverse demands.

Methods

Energy system analysis is conducted using the PyPSA-Eur model (Brown et al., 2018), enabling an endogenous assessment of investment decisions in new infrastructures while covering demand from multiple sectors, including electricity, heat, agriculture and transport. The model integrates GIS-based data for sinks and sources of carbon dioxide and hydrogen, existing network infrastructures for natural gas, oil, and oil-based products, as well as potential locations for underground storage in the European region. Techno-economic data is taken from the open-source database (Victoria et al. 2024).

For the planning of CO_2 networks in the context of carbon management, this study maps CO_2 quantities from hard-to-abate industries such as cement, waste incineration facilities, biogenic carbon sources and balances them via permanent sequestration and utilisation through the production of synthetic feedstocks such as methanol, FT crude, or FT naphtha, or synthetic products such as fuels (kerosene, diesel) or high value chemicals. For the evaluation of a hydrogen network development, we assess the complete energy system with focus on hydrogen demand, hydrogen transport infrastructure and hydrogen production from renewable energy sources as well as low carbon hydrogen from steam methane reformer (SMR) coupled with carbon capture. A scenario-based approach is applied to capture the impact of different demand variations, policy drivers and technology costs on infrastructure layouts. Sensitivity analyses further explore the impact of technological and economic uncertainties on the optimised network configurations.

Results

The expected outcome is to show the repurposing potential of the existing pipeline infrastructure as well as develop new pipeline networks for hydrogen and carbon dioxide in the context of energy transition in the North Sea region:

- Optimised topologies for CO_2 and hydrogen transport to identify key pipeline infrastructure transition corridors for gas and oil infrastructure owners.

- Shadow prices of hydrogen and synthetic fuels, including not only the low carbon hydrogen supply chain but also the sustainable carbon supply chain.

- Insights into the interdependencies between CO_2 and hydrogen transport systems, highlighting their synergies in achieving net zero targets.

- Implications on hydrogen and CO_2 pipeline infrastructure requirements driven by scenario-based and site-specific demand for synthetic fuels and HVC.

Conclusions

The study highlights the strategic importance of cross-sector infrastructure planning to achieve cost-effective decarbonisation. Reused oil and gas pipelines offer a viable path for early hydrogen and CO_2 pipeline routes, but their long-term role depends on a coordinated policy framework and reliable signals on demand growth. By exploring different scenarios for the location of future hydrogen and synthetic fuel demand, more knowledge can be gained to inform strategic decisions for European industry.

References

Hofmann, Fabian; Tries, Christoph; Neumann, Fabian; Zeyen, Elisabeth; Brown, Tom (2024): H2 and CO2 Network Strategies for the European Energy System. Available online at http://arxiv.org/pdf/2402.19042v2.

Brown, T., Hörsch, J., & Schlachtberger, D. (2018). PyPSA: Python for Power System Analysis. Journal of Open Research Software, 6(1), 4. DOI: 10.5334/jors.188

Victoria, Marta; Zhu, Kun; Zeyen, Elisabeth; Brown, Tom: Technology-data base — technology-data. Available online at https://technology-data.readthedocs.io/en/latest/.