Planning a CO_2 Pipeline Network for Industry in North Rhine-Westphalia

Bobby Xiong[1], **Khaled Al-Dabbas**[2], **Tobias Fleiter**[2]

[1]TU Berlin, Digital Transformation in Energy Systems [2]Fraunhofer Institute for Systems and Innovation Research ISI

resilient-project.github.io · pypsa.org · github.com/resilient-project/nrw-study

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Model & data

Full presentation (PDF)

Motivation

North Rhine-Westphalia (NRW) hosts much of Germany's steel, cement, lime, chemical and waste incineration capacity. Part of their process emissions is unavoidable, so carbon capture, transport, storage and use (CCS/CCU) are needed for climate neutrality by 2045. Without domestic storage, captured CO_2 can be piped to the North Sea, and NRW lies on the route from southern Germany. In this RESILIENT case study (TU Berlin, Fraunhofer ISI, IN4climate.NRW), we ask:

- How should a **CO_2 pipeline network** in NRW and Germany be built up, and how is it used?
- How do the planned **PCI-PMI** CO_2 pipeline projects compare with an **endogenously optimised** network?
- How much CO_2 **passes through** NRW from other regions?

Scenarios

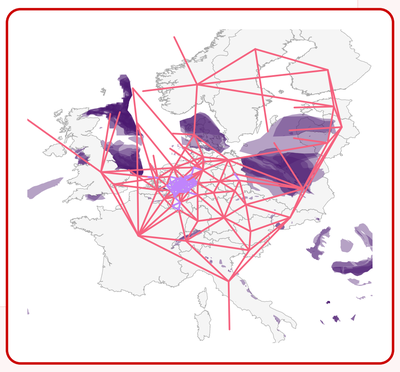
Industrial demand and emissions come from the bottom-up model FORECAST [2], soft-linked into PyPSA-Eur. **HtA+** keeps more fossil routes in place (steam crackers, CH_4-based direct reduction, blast furnaces) and extends the adoption of carbon capture.

Industry pathway	**HtA**: waste incineration, cement, lime	**HtA+**: also chemicals, process heat, steel
CO_2 pipelines	PCI-PMI	endogenous optimisation
CO_2 storage	offshore (North Sea)	+ onshore
	PCI-PMI baseline	endogenous pipelines
	1.a	1.b
		more capture (HtA+)
		2.a
		onshore storage
		2.b

Model setup

We use the open-source, sector-coupled model PyPSA-Eur [4, 6, 3], covering all energy sectors in around 80 regions: NRW by county (NUTS3), the rest of Germany by state, and 19 neighbouring countries.

- Myopic 2035–2040–2045, 1460 time steps per year; planned power grid, H_2 pipelines optimised.
- Offshore storage at 30 €/t, 100–250 Mt/a.
- Pipeline candidates on a Delaunay graph (right), rounded to DN400 (≈ 9 Mt/a) or DN700 (≈ 28 Mt/a).



CO_2 network

In 2045, NRW's steel, refinery and cement sites are connected to a network that leads mainly west towards the Netherlands and north towards Bremen, and from there to offshore storage in the North Sea (Fig. 1). Some routes appear in all scenarios, e.g. the westward corridor to the Netherlands and Belgium and the transit corridors in south-eastern NRW. Some captured CO_2 stays in NRW as feedstock for methanol and Fischer-Tropsch fuels.

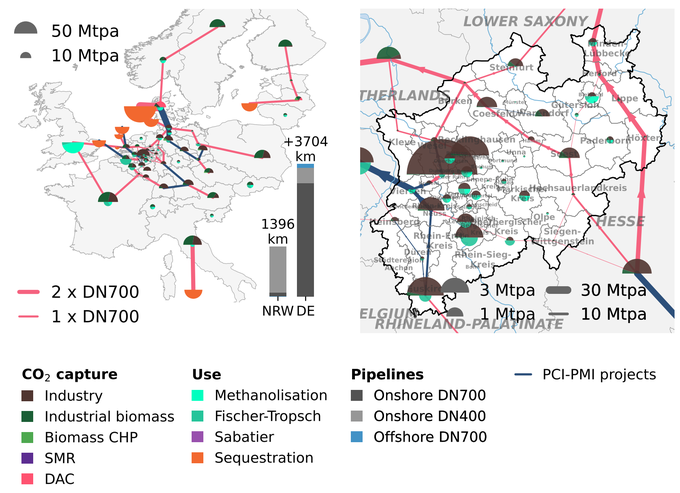


Figure 1: Scenario 2.a (HtA+, endogenous pipelines), 2045: CO_2 capture (upper half-circles) and use or storage (lower half-circles), pipeline capacities in Europe (left) and annual net CO_2 flows in NRW (right, arrows: flow direction). Blue: PCI-PMI projects.

Pipeline sizing

The fixed PCI-PMI network (1.a) has about 4 400–4 600 km of pipelines in Germany, but its onshore DN400 pipes run below 15 % of capacity in every year. With endogenous expansion (1.b), the network is 2 300–2 700 km long and better utilised. DN700-equivalent pipes are enough for transport between regions, and offshore collector lines run at constantly high utilisation (Fig. 2).

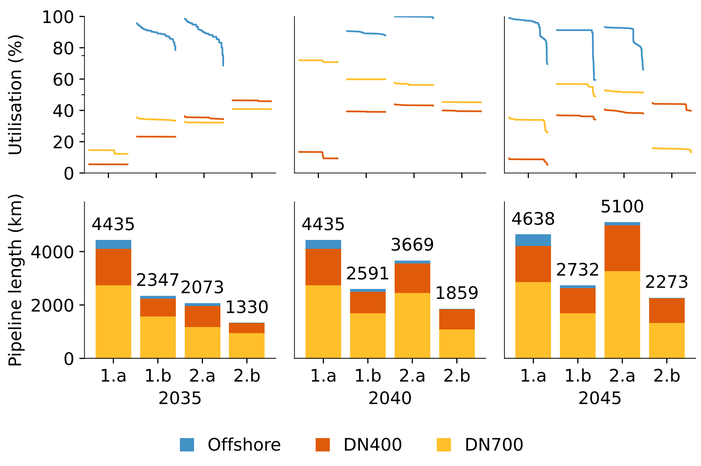


Figure 2: Germany (incl. NRW): annual utilisation duration curves per pipeline (top) and pipeline lengths by type (bottom).

CO_2 transit through NRW

Much of the CO_2 crossing NRW's borders is **transit** from Hesse, Rhineland-Palatinate and southern Germany. We derive transit from the hourly pipeline flows with proportional-sharing flow tracing [1, 5]; the whiskers in Fig. 3 show the possible range.

- In 2045, 23–46 Mt/a of CO_2 pass through NRW in the offshore-only scenarios (1.a–2.a). Almost all imported CO_2 leaves NRW again.
- In HtA+ (2.a), NRW's own exports grow to about 41 Mt/a on top of transit.
- With onshore storage (2.b), transit almost disappears (below 5 Mt/a).

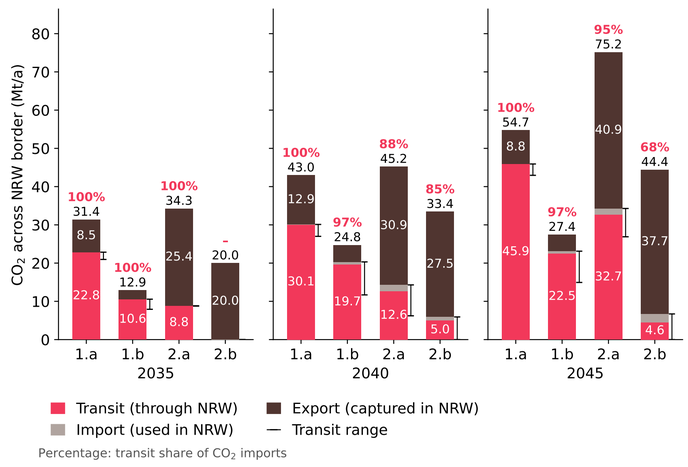


Figure 3: CO_2 flows across the NRW border: transit (red), imports used in NRW (grey) and exports of CO_2 captured in NRW (brown). Percentages: transit share of CO_2 imports into NRW.

System costs

An optimised pipeline network lowers annual European system costs by 19–26 bn € compared with the fixed PCI-PMI network (1.b vs. 1.a), mainly through lower CO_2 infrastructure costs and less DAC. Onshore storage (2.b) saves a further ∼8 bn €/a compared with 2.a in 2045 and more than halves the pipeline investment (Fig. 4).

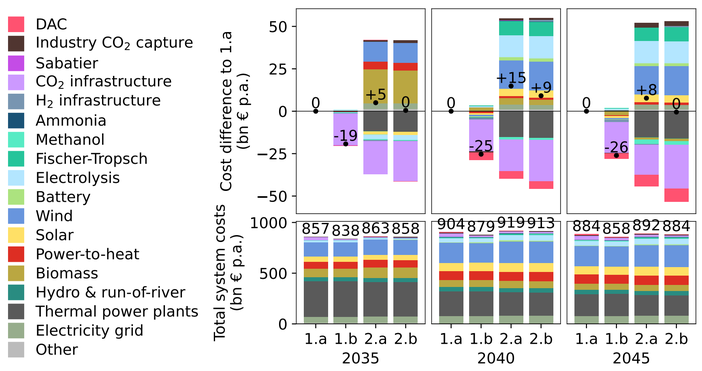


Figure 4: Cost difference to scenario 1.a (top) and total annualised system costs (bottom) in bn €/a.

Take-aways

1. **Robust corridors**: the westward link to the Netherlands and Belgium and the transit corridors in south-eastern NRW appear in all scenarios.
2. **NRW: start small**, with 1–2 DN400 feeder pipes (≈ 9 Mt/a each), connecting the largest emitters first: steel, then refineries and cement.
3. **NRW is a transit hub**: up to 46 Mt/a of CO_2 from other regions crosses NRW unless onshore storage is available.
4. **PCI-PMI CO_2 projects are oversized**, mainly in capacity and slightly in length. DN700-equivalent pipes (≈ 28 Mt/a) are enough between regions; offshore collection points need larger or parallel pipes.
5. **Onshore storage** in Germany and neighbouring countries more than halves pipeline investment and saves ∼8 bn €/a.
6. **Capture and DAC**: well-sized capture units can run above 70 % utilisation (15–50 Mt/a in NRW, 60–130 Mt/a in Germany). DAC is built mainly in neighbouring countries, and an optimised network beyond PCI-PMI greatly reduces Europe's DAC needs.
7. **CCU and DAC alone are not enough**: transport, storage and local use are all needed, including to supply aviation and shipping fuels.

This work was supported by the German Federal Ministry for Economic Affairs and Energy (BMWE) under Grant No. 03EI4083A (RESILIENT). This project has been funded by partners of the CETPartnership (https://cetpartnership.eu) through the Joint Call 2022. As such, this project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement no. 101069750.

[1] Janusz Bialek. Tracing the flow of electricity. *IEE Proceedings - Generation, Transmission and Distribution*, 143(4):313–320, 1996.

[2] Tobias Fleiter, Matthias Rehfeldt, Andrea Herbst, Rainer Elsland, Anna-Lena Klingler, Pia Manz, and Stefan Eidelloth. A methodology for bottom-up modelling of energy transitions in the industry sector: The FORECAST model. *Energy Strategy Reviews*, 22:237–254, 2018.

[3] Fabian Hofmann, Christoph Tries, Fabian Neumann, Elisabeth Zeyen, and Tom Brown. H2 and CO2 network strategies for the European energy system. *Nature Energy*, pages 1–10, April 2025.

[4] Jonas Hörsch, Fabian Hofmann, David Schlachtberger, and Tom Brown. PyPSA-Eur: An open optimisation model of the European transmission system. *Energy Strategy Reviews*, 22:207–215, November 2018.

[5] Jonas Hörsch, Mirko Schäfer, Sarah Becker, Stefan Schramm, and Martin Greiner. Flow tracing as a tool set for the analysis of networked large-scale renewable electricity systems. *International Journal of Electrical Power & Energy Systems*, 96:390–397, 2018.

[6] Fabian Neumann, Elisabeth Zeyen, Marta Victoria, and Tom Brown. The potential role of a hydrogen network in Europe. *Joule*, 7(8):1793–1817, August 2023.

Contact: Bobby Xiong (xiong@tu-berlin.de) **Keywords:** open-source · energy system modelling · carbon capture · CO_2 pipelines · industry · North Rhine-Westphalia · PCI-PMI