Paper presentation at ENERDAY 2026

Industrial hydrogen demand and decentralized supply in North Rhine-Westphalia (NRW): a cluster-based spatial scenario analysis towards net-zero production by 2045

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Dresden, 27.03.2026

Agenda

1. Introduction
2. Methodology
3. Main results
4. Comparison with other studies
5. Conclusion

Role of H_2 in Decarbonizing Germany's Industry: Why NRW Matters

[1] Engelbert Reineke, CC BY-SA 3.0 DE
[2] Bodoklecksel, CC BY-SA 3.0
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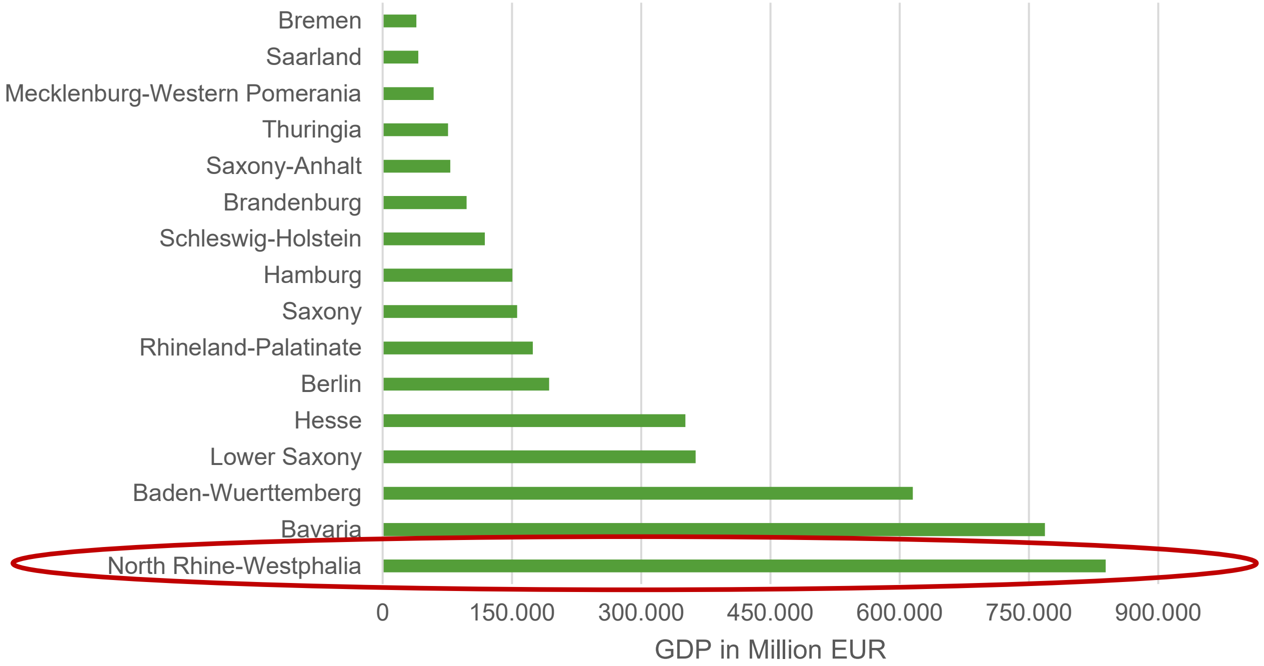


Figure 1–1: German Federal States and Their GDP in 2023 [Data: See Sources]

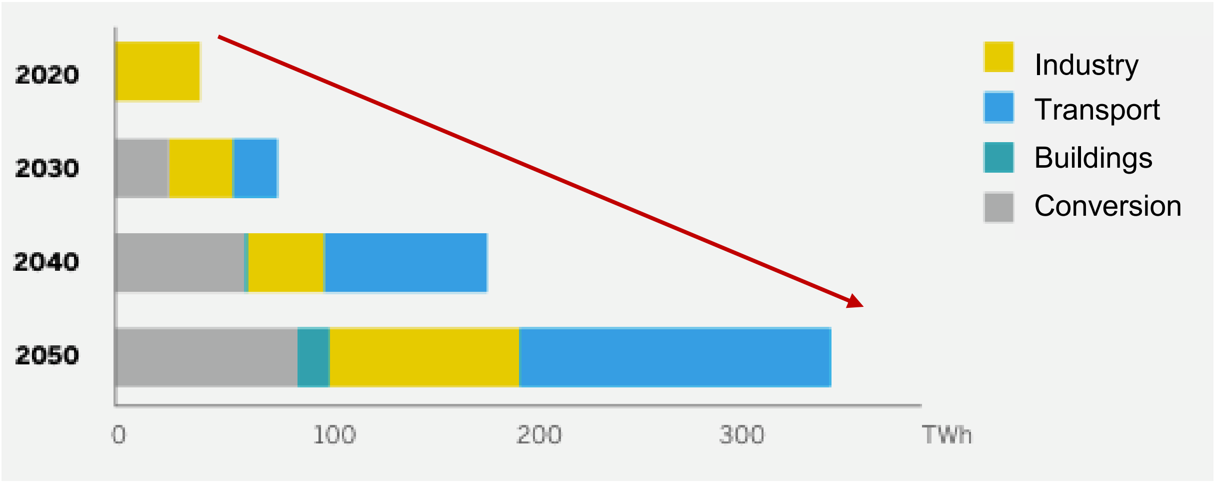


Figure 1–2: NRW's Hydrogen Demand until 2050 (MWIKE NRW, 2020)

Source: Figure 1-2 – Own illustration, data from Statistische Ämter des Bundes und der Länder (2024)
MWIKE NRW (2020)

The Challenge: Reducing Industrial GHG Emissions to Net Zero until 2045

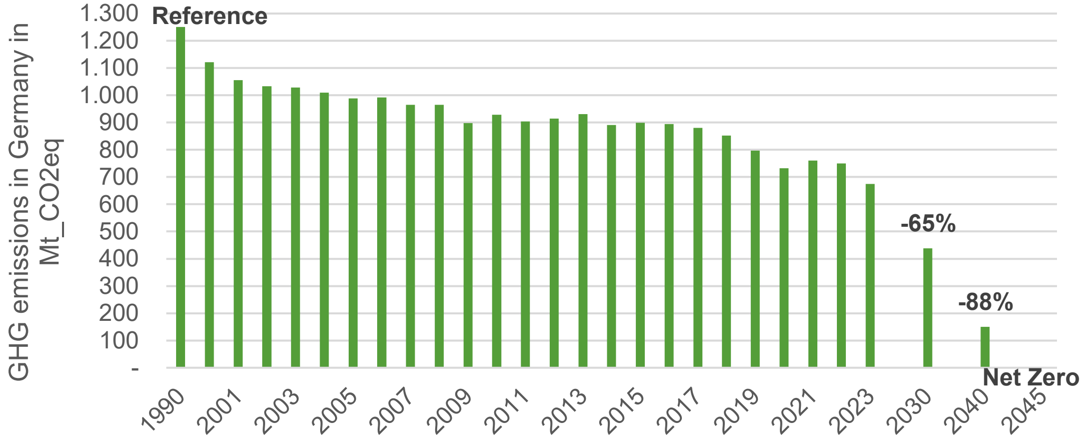


Figure 1–3: Greenhouse gas emissions and national reduction targets [Data: See sources]

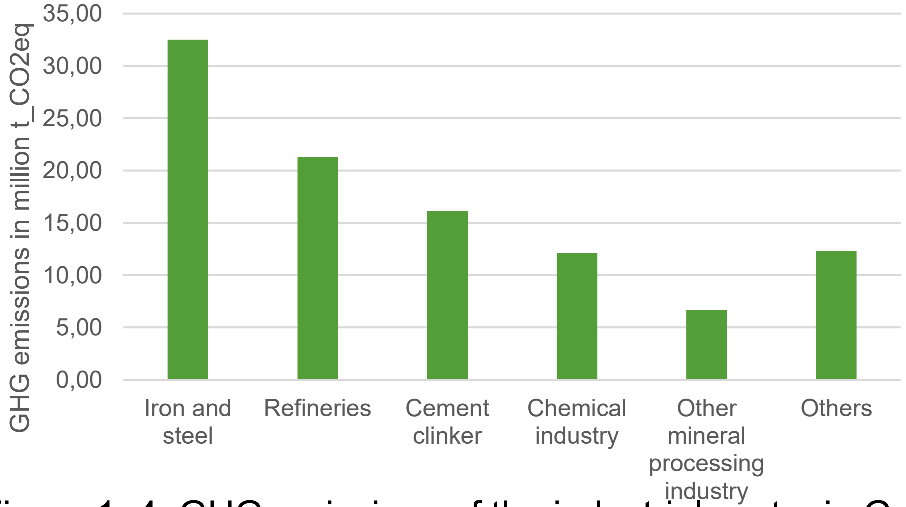


Figure 1–4: GHG emissions of the industrial sector in Germany by industry in 2023 [Data: See Sources]

1) **Germany's industry accounts for high GHG emissions: 29 % of final energy consumption was accounted by industry in 2021**
2) **Most of Germany's emissions are emitted in NRW**
3) **Hydrogen will play key role in net zero industrial transformation**

→ How much hydrogen will be needed in industrial processes in the future to fulfil Germany's net zero goal?

Source: Figure 3 – Own illustration, data from Umweltbundesamt (2024)
Figure 4 – Own illustration, data from Umweltbundesamt & Deutsche Emissionshandelsstelle (2024)
AGEB (2024); Statistische Ämter des Bundes und der Länder (2023);

100 years hydrogen in NRW: historical backbone and future key

Hydrogen Infrastructure Development in a Highly Industrialized Region: Historical Analysis of the Hydrogen Network in North Rhine-Westphalia

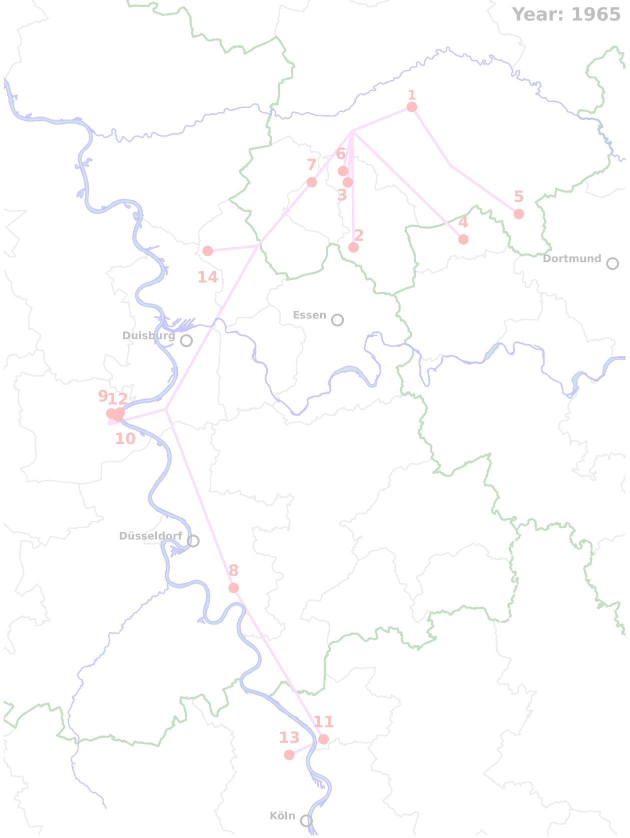


Figure 1–5: Historical development of the hydrogen network by 1965.
For more information refer to the paper draft.

Industrial hydrogen demand and decentralized supply in North Rhine-Westphalia (NRW): a cluster-based spatial scenario analysis towards net-zero production by 2045

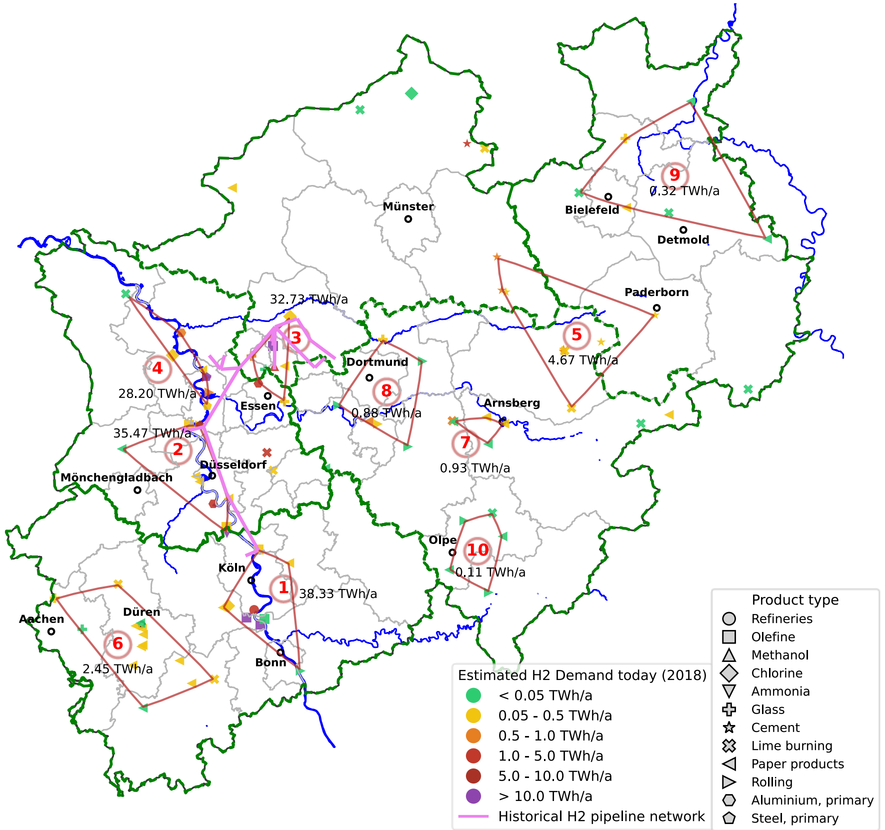


Figure 1–6: Industrial hubs, clusters in NRW and their hydrogen potential today.
For more information refer to Dreher & Gast (2026).

Source: Figure 1-1: Dreher et al. (2026), in review
Figure 1-2: Dreher & Gast (2026)

Identified Research Questions

<u>Existing studies focus on:</u>

- System-level focus, no site-specific linkage
- National level, no spatial disaggregation
- sectoral averages, no process-level detail
- No demand clusters, no local supply potentials in NRW

→ **Core gap**: missing spatial coupling of supply and demand; no disaggregation

→ Decentralized supply approaches are not analyzed

Research Question

1) Which energy-intensive industries exist in NRW, and how are they spatially distributed?

Research Question

2) What is the expected hydrogen demand for these industries today, in the medium-term (~2030), and long-term (~2045) in a zero-carbon energy system?

Research Question

3) Can this hydrogen demand be met through decentralized production, and what are the implications?

2. Methodology
Steps of the Analysis

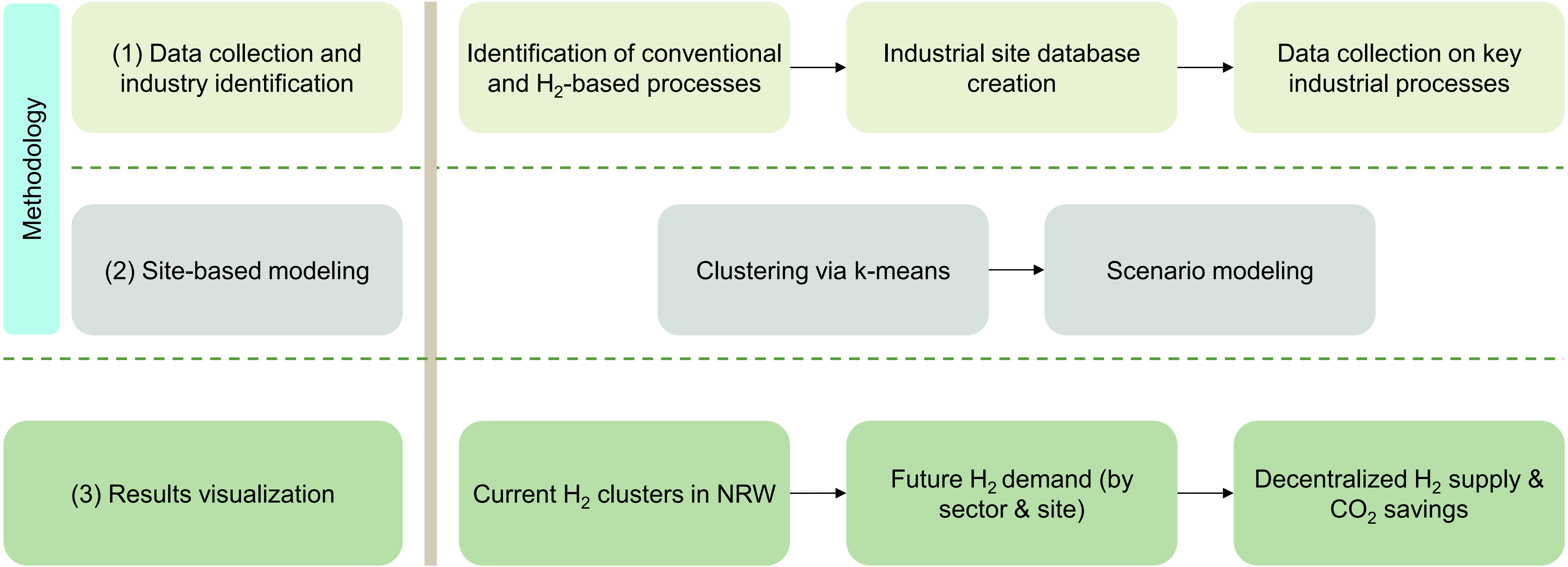


Figure 2–1: Overview of the methodological approach of the analysis and its results with its main steps to cover and answer the defined research gaps and questions.

Source: Dreher & Gast (2026)

3.1 Results - Spatial demand structure of industrial hydrogen use cases today

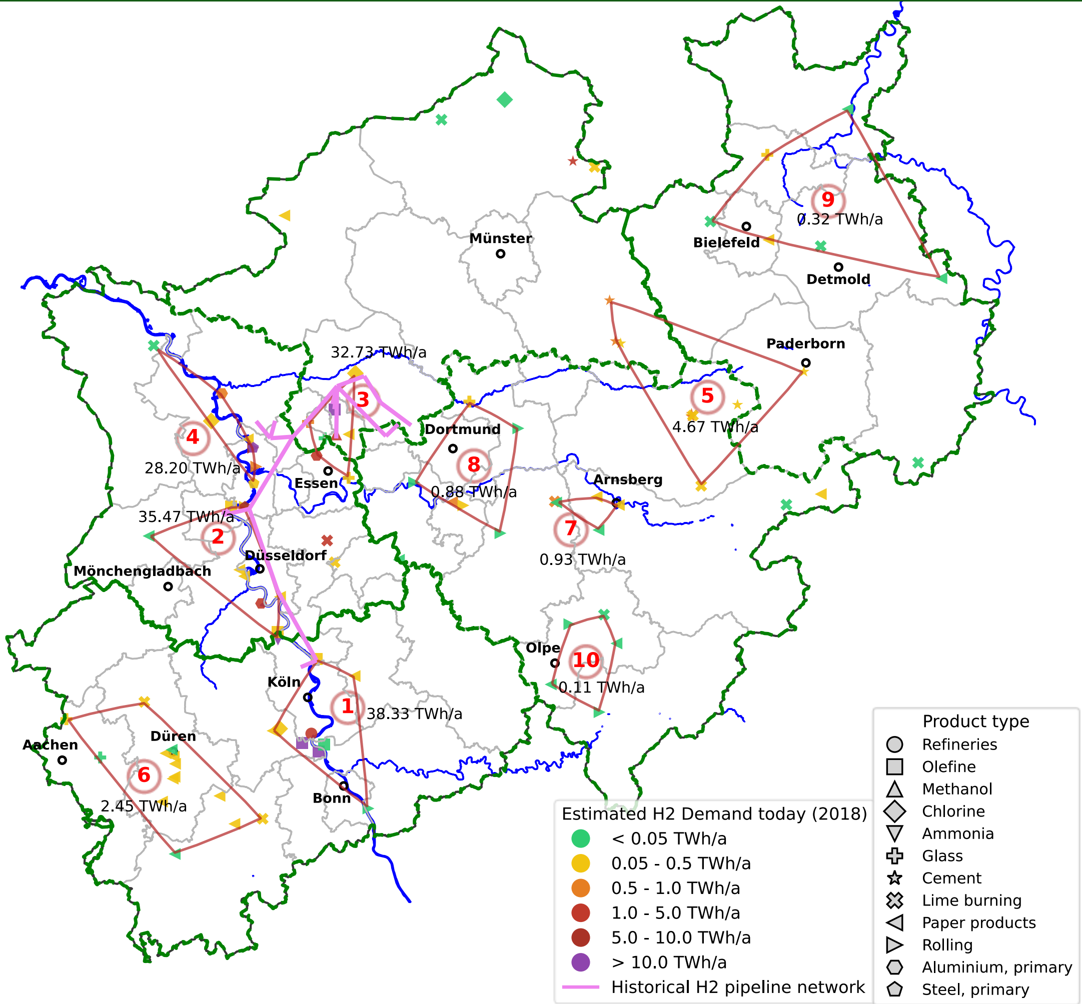


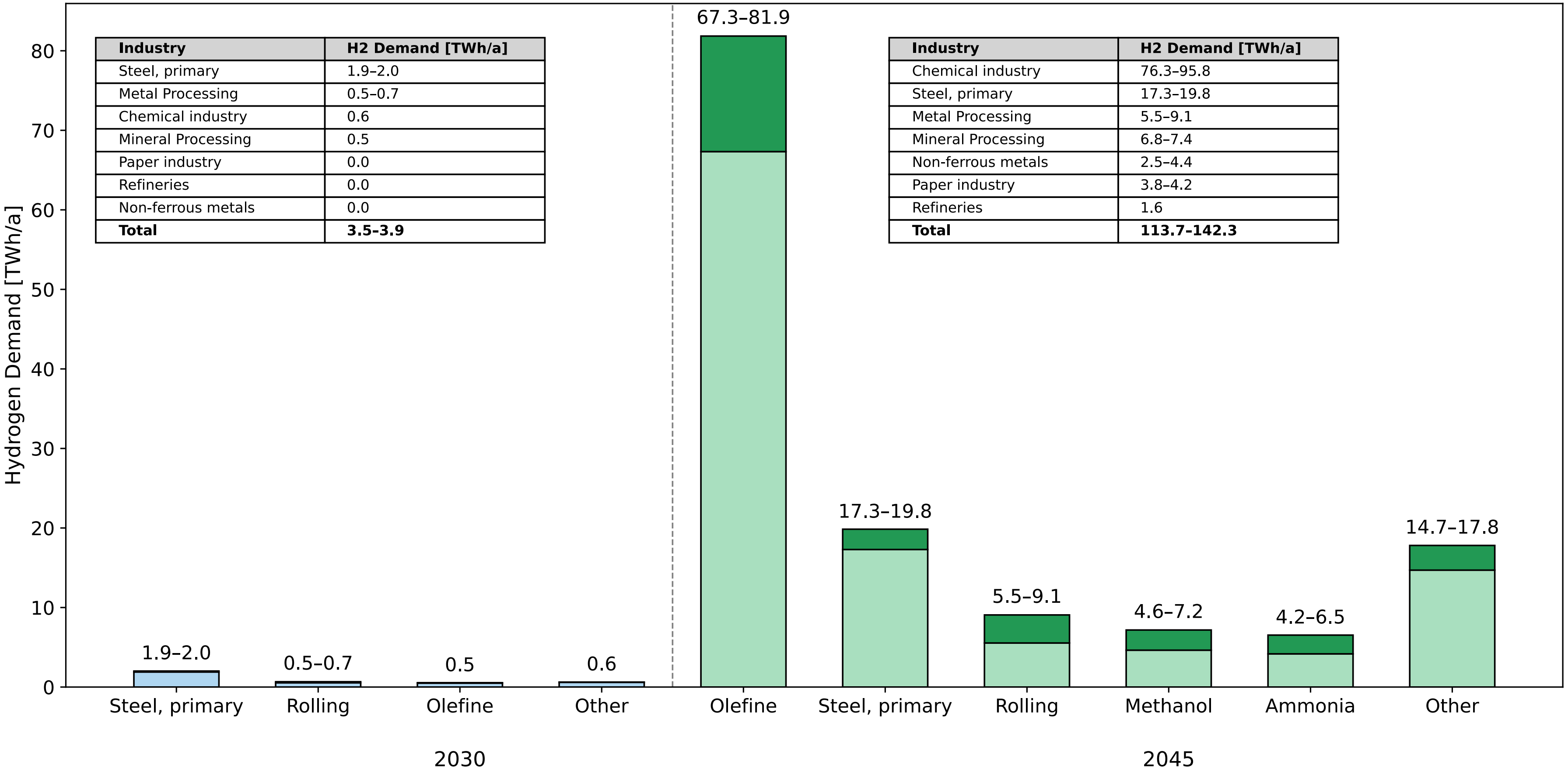
Figure 3–1: Industrial hubs and clusters in NRW, their locations and calculated hydrogen potential today (2018). Own illustration based on a k-means algorithm conducted on own database. Database included in supplementary materials.

	Cluster potential H2 demand [TWh/a]		Number of sites
Cluster 1 (chemicals/Köln)	38.33	25.98 %	9
Cluster 2 (chemicals & steel/Düsseldorf)	35.47	24.05 %	10
Cluster 3 (chemicals/Essen)	32.73	22.19 %	8
Cluster 4 (chemicals & steel/Duisburg)	28.20	19.12 %	8
Cluster 5 (cement/Soest)	4.67	3.16 %	10
Cluster 6 (paper/Düren)	2.45	1.66 %	14
Cluster 7 (paper/Arnsberg)	0.93	0.63 %	5
Cluster 8 (metal processing/Dortmund)	0.88	0.59 %	6
Cluster 9 (mixed/Detmold)	0.32	0.22 %	6
Cluster 10 (mixed/Olpe)	0.11	0.08 %	5
no cluster (dispersed)	3.41	2.31 %	11
Total	147.51	100.00 %	92

Table 3–1: Potential hydrogen demand of industrial clusters and selected industries in NRW. Calculated on basis of the database. For more data, refer to supplementary material.

Source: Dreher & Gast (2026)

3.2 Results - Future hydrogen demand in NRW in 2030 & 2045



Industry	H2 Demand [TWh/a]
Steel, primary	1.9–2.0
Metal Processing	0.5–0.7
Chemical industry	0.6
Mineral Processing	0.5
Paper industry	0.0
Refineries	0.0
Non-ferrous metals	0.0
Total	**3.5–3.9**

Industry	H2 Demand [TWh/a]
Chemical industry	76.3–95.8
Steel, primary	17.3–19.8
Metal Processing	5.5–9.1
Mineral Processing	6.8–7.4
Non-ferrous metals	2.5–4.4
Paper industry	3.8–4.2
Refineries	1.6
Total	**113.7–142.3**

Figure 3–2: Estimated future hydrogen demand in energy-intensive industries in NRW in 2030 and 2045 by industry sector and products. The ranges reflect the different scenario results.

→ Primary steel production determines hydrogen demand in 2030
→ Chemicals dominate long-term demand
→ S-curve adoption; delayed chemicals uptake due to high costs

Source: Dreher & Gast (2026)

3.3 Results - Decentralized hydrogen supply

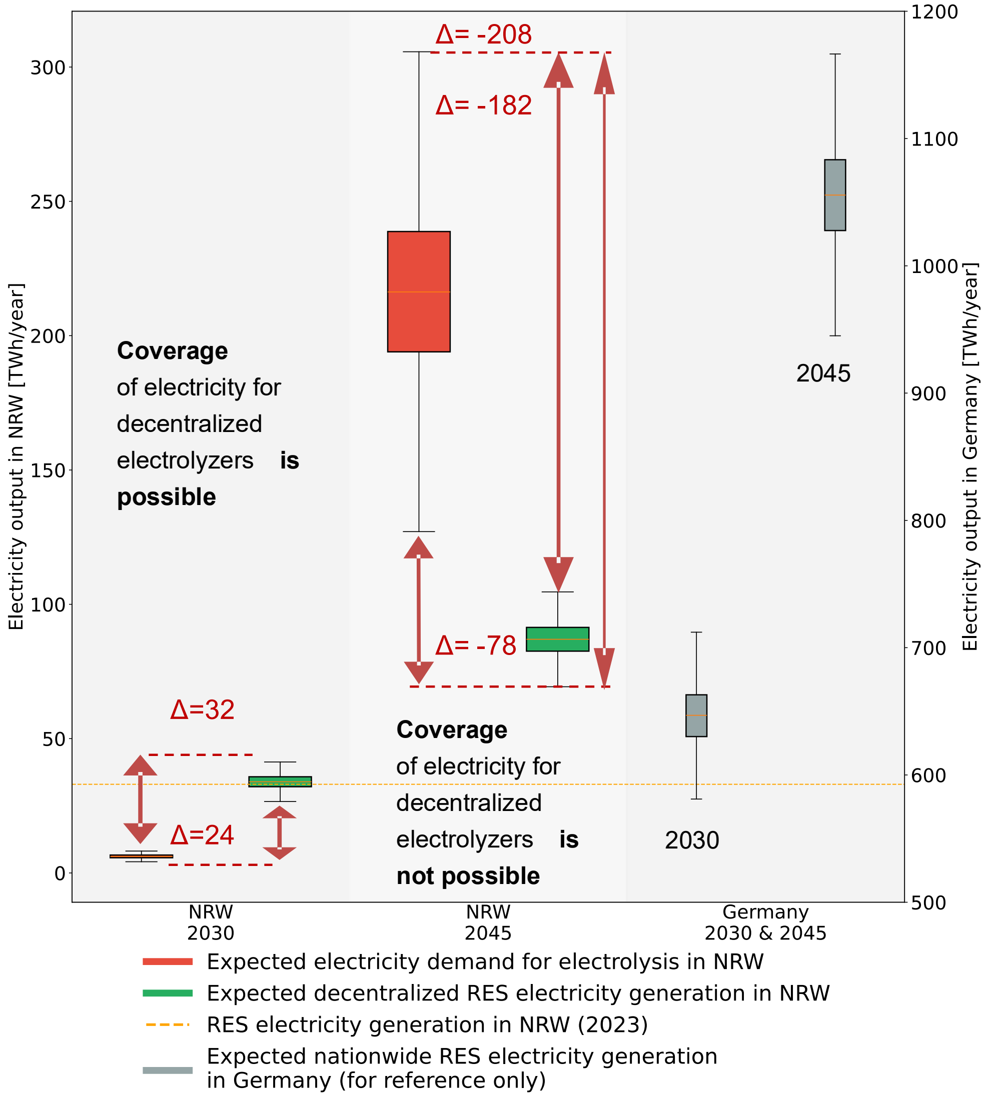


Figure 3–3: Renewable electrolyzer supply gap: delta and coverage of electricity demand for decentralized hydrogen production and projected renewable electricity generation in NRW for the years 2030 and 2045 under varying efficiency and scenario assumptions.

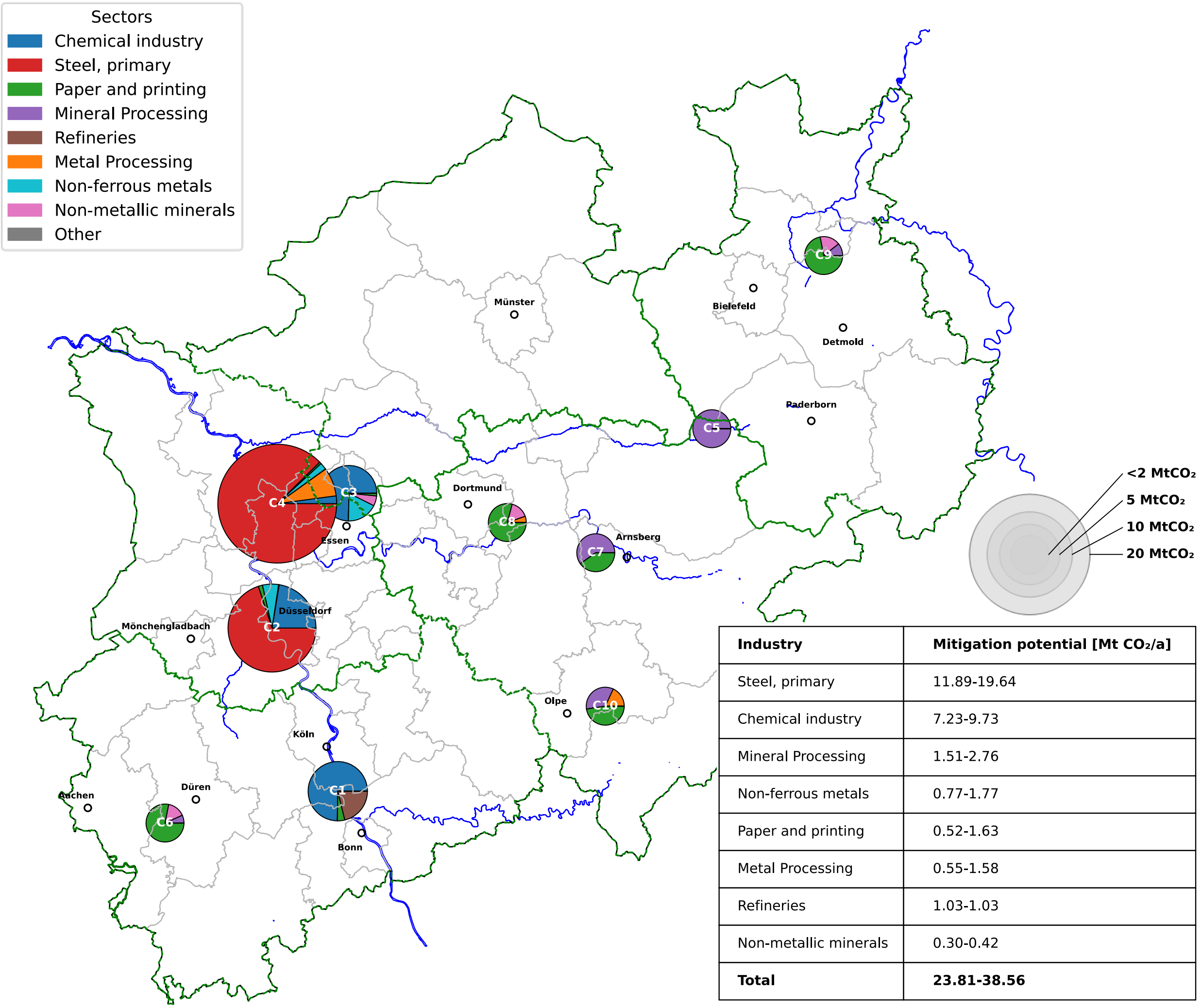
- Full decentralized coverage possible in 2030
- Full coverage unlikely in 2045 under conservative assumptions
- Other sectors (e.g. buildings, transport) also requires RES → competition for electricity

→ decentralized approach is possible on a transitional basis for 2030, but not for 2045

Source: Dreher & Gast (2026)

3.4 Results - Emissions mitigation potential

Figure 3–5: Estimated annual CO_2 mitigation potential per industrial cluster in 2045, differentiated by sector.



Industry	Mitigation potential [Mt CO_2/a]
Steel, primary	11.89-19.64
Chemical industry	7.23-9.73
Mineral Processing	1.51-2.76
Non-ferrous metals	0.77-1.77
Paper and printing	0.52-1.63
Metal Processing	0.55-1.58
Refineries	1.03-1.03
Non-metallic minerals	0.30-0.42
Total	**23.81-38.56**

- Mitigation potential of each sector is calculated for the year 2045
- Primary steel contributes > 50 % of total mitigation
- Other high-impact products: olefine, cement, rolling, paper products
- **2045 values reflect full H2 substitution**

→ Hydrogen deployment could achieve high emission mitigation potentials

Source: Dreher & Gast (2026)

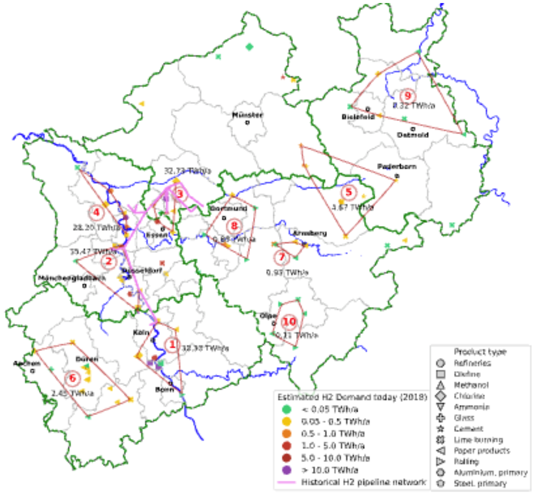
Positioning this study within existing demand estimates

Study	Scenario	Focus region	Year	Scope	Industrial H_2 demand [TWh] In NRW	Industrial H_2 demand [TWh] In Germany	Comment
This study	Transformative (A), incremental (B), regressive (C) scenarios	NRW	2045	Full H_2 substitution and feedstock use	114–142	–	Full H_2 substitution in energetic and feedstock use results in an upper bound; Output developments through industries differ in scenarios
Prognos et al. [16]	KNDE2045	Germany	2045	Mixed-tech pathways	30 *	74	Strong declining output in chemicals, partial feedstock use of H_2 and mixed-tech pathways
BCG [32]	Klimapfade 2.0 Zielpfad	Germany	2045	Mixed-tech pathways	40 *	100	Strong declining output in chemicals, partial feedstock use of H_2 and mixed-tech pathways
dena [34]	KN100	Germany	2045	Mixed-tech pathways	76 *	190	Mixed-tech pathway but similar industry assumptions
Consentec et al. [33]	O45–H2	Germany/ NRW	2045	Full H_2 substitution and feedstock use	145	442	Similar upper bound, assumes full hydrogen substitution and feedstock use in chemicals. Includes more products, though these have a much lower hydrogen requirement.
Cerniauskas et al. [31]	–	NRW	2050	Full H_2 substitution, no feedstock use	94	–	Similar scope as this study, comparable industry assumptions
MWIKE NRW [13]	–	NRW	2050	Full H_2 substitution and feedstock use	172	–	Similar scope as this study, comparable industry assumptions. Hydrogen is used both, energetic and feedstock in chemicals

Table 4–1: Comparison of future hydrogen demand scenarios and this study. Different scenarios for a climate-neutral Germany and NRW. Table based on studies compared by Stiftung Klimaneutralität (2022) and further modified with by Alekseev et al. (2023), BCG (2021), Consentec et al. (2024), dena (2021), Cerniauskas et al. (2021), MWIKE NRW (2020) and Prognos et al. (2021). NRW-specific values marked with (*) are not explicit given in the study and calculated with a 40 % NRW-share as described in the paper.

Source: Dreher & Gast (2026)

Conclusion



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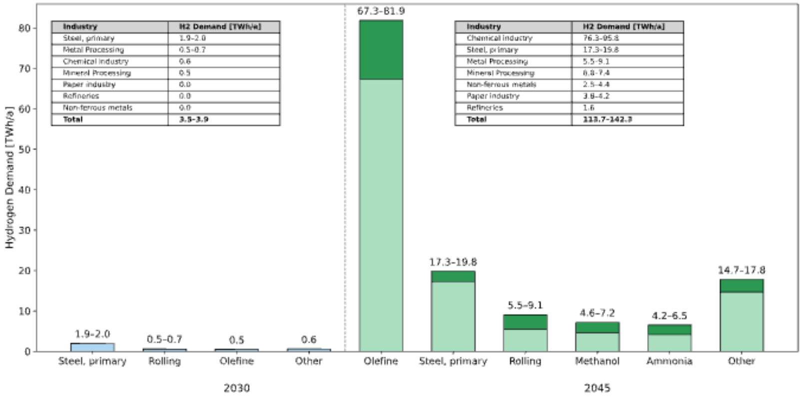

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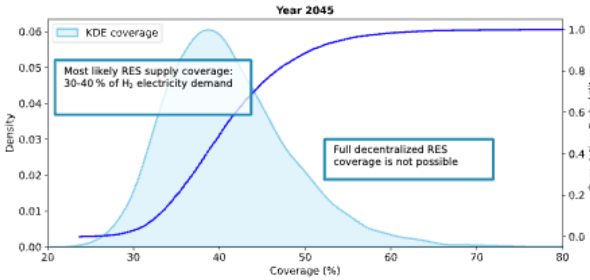

Figure 3–4: Kernel density estimation and cumulative probability of covering the electricity demand for electrolysis with decentralized renewable electricity generation in NRW.

- Monte Carlo simulation with 10.000 iterations
- Full coverage by decentralized RES nearly impossible
- Gap widens due to demand, despite RES expansion
- Most likely coverage in 2045: 30-40 %
- Nevertheless, partial coverage through decentralized provision could be a partial strategy

→ Without additional measures – such as cross-sectoral coordination, electricity imports, or revised RES targets – current planning trajectories fall short of enabling full decarbonization by 2045

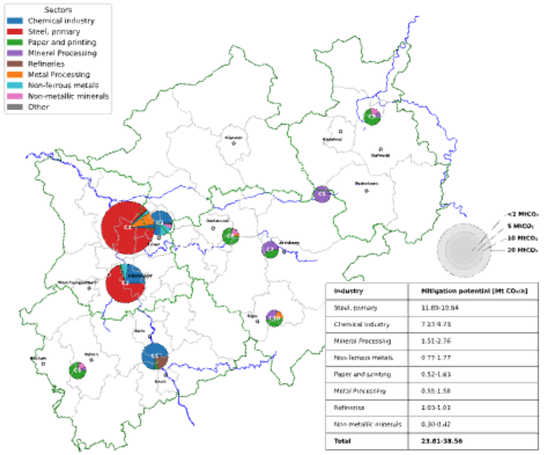

Figure 3–5: Estimated annual CO_2 mitigation potential per industrial cluster in 2045, differentiated by sector.

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- Other high-impact products: olefine, cement, rolling, paper products
- **2045 values reflect full H2 substitution**

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Thank you for your attention!

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