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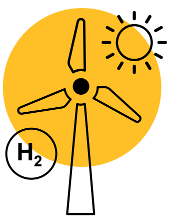
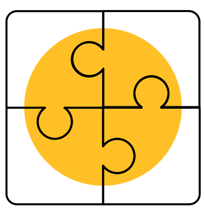
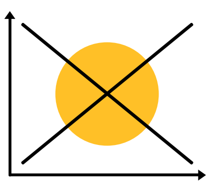
[EWI Policy Brief]

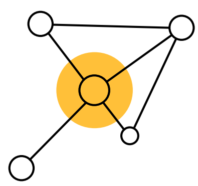
Stronger together: How hydrogen clusters can drive the market ramp-up in Germany

August 2023









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Core Statements

- In hydrogen clusters, step-by-step innovations along the value chain can enable the economic development of the new market and cost reduction thanks to economies of scale.
- Clusters can increase productivity, boost innovation, and facilitate the establishment of companies. There is a consensus at both the academic and political levels that the hydrogen market ramp-up can be efficiently managed with the help of clusters.
- In order to promote clusters in a targeted manner, regions must be identified that appear particularly suitable as locations for hydrogen clustering. The identification criteria presented in this policy brief from the areas of hydrogen demand, production, infrastructure, and research and education help in this process.
- For now, no cluster formation can yet be identified in hydrogen projects that have already been realized in Germany. If, on the other hand, planned projects and projects under construction are considered, four regions stand out in which a concentration can be observed. However, since only a few projects have reached the final investment status so far, it is difficult to foresee where hydrogen clusters will actually form.
- **Recommendations for action:**
  - In order to support the emergence of hydrogen clusters, regions with good cluster potentials would first have to be identified. The defined identification criteria help in this process.
  - In addition, decision-makers would have to prioritize regions with good prerequisites for cluster formation in order to be able to use supporting measures and financial support in a targeted manner.
  - Finally, focused political support should be provided at various levels. In addition to financial support, good political communication, the strengthening of responsible offices, and support for the education and training of specialists can help to establish hydrogen clusters.

Background

To achieve climate neutrality, existing energy and industrial processes must be decarbonized. Since direct electrification is not economically efficient or technically feasible in all sectors, the use of low-carbon hydrogen is important. Especially in the chemical industry and in primary steel production, low-carbon hydrogen is considered necessary to reduce emissions effectively.

For a successful market ramp-up of low-carbon hydrogen, production, demand, and infrastructure need to be developed simultaneously. This poses a complex problem for actors along the entire value chain, also known as the "three-sided chicken-and-egg problem": Without sufficient supply, demand will not develop, without demand, there will be no supply, and without a well-developed transport infrastructure, efficient and liquid trade over long distances is not possible (Schlund, Schulte & Sprenger, 2022).

A major obstacle in the hydrogen market ramp-up is the expansion of hydrogen infrastructure to meet demand. However, the need for infrastructure can be reduced by a local concentration of supply and demand. So-called "hydrogen clusters" could drive the market ramp-up through organic growth using network effects and economies of scale (EWI, 2023). This is particularly relevant for the targeted short-term hydrogen market ramp-up in Germany and Europe by 2030.

In the following, the importance of clusters for the hydrogen market ramp-up is explained, and recommendations for action for the short-term development of hydrogen clusters in Germany are given. For this purpose, the general advantages of industrial clusters are described, and criteria for identifying relevant hydrogen clusters are defined.

Definition of clusters

The analysis of clusters in the market ramp-up of new technologies is well-established in the academic literature. A cluster in a particular field is the geographical concentration of interconnected companies, specialized suppliers, service providers, related institutions (e.g., universities, standards institutes, trade associations), or companies in related industries.

The actors in a cluster can both compete and cooperate so that in addition to direct competition, there is also cooperation along the value chain. Competition arises in particular at the horizontal level (e.g., competition for customers) and cooperation at the vertical level (e.g., deliveries or services). Both aspects favor local concentration, as strong competition between companies can attract upstream and downstream industries and service providers, and cooperation along the value chain consolidates this concentration (Porter, 2000).

The geographical scope of clusters can range from a region or a single city to neighboring countries (e.g., southern Germany and German-speaking Switzerland). This scope refers to the distance over which advantages regarding information, transactions, incentives, and other efficiencies hold (Porter, 2000).

In the context of a hydrogen market, a cluster would include electrolysis operators, infrastructure operators, industrial and private customers, service providers, and the settlement of academic research institutes. Step-by-step innovations along the value chain can enable both the economic development of a new market and cost reductions thanks to economies of scale. These effects can arise from complementary developments (e.g., developments in the transport infrastructure could open up new applications) or from competitive innovation pressure (e.g., price competition in hydrogen production) (EWI, 2023).

Advantages of clusters

Clusters offer several benefits regardless of the good or service produced. These can be divided into three areas:

- **Higher productivity**: The regional proximity of many actors in a sector enables better access to specialized inputs of the production process, such as components, machines, services, and skilled labor. In addition, access to information and (quasi-)public goods, such as shared infrastructure, is facilitated through personal relationships and institutionalized communities (Porter, 2000).

- **Increased innovative strength**: Actors within clusters have a heightened awareness of the possibility as well as the need for innovation by observing competitors. Through a cluster of buyers, they gain quicker insight into new customer needs. At the same time, new materials and services are more accessible. In cooperation with local partners such as research institutes, the learning process and knowledge transfer can be accelerated through site visits and personal contact (Porter, 2000; Asheim & Gertler, 2006; EWI, 2023).
- **Simplified company formation:** In clusters, stakeholders have better information about new business areas and gaps in the value chain. The effort required to establish a cluster is lower, as the necessary assets, knowledge, materials, and employees are more easily available. A network of customers and suppliers is available due to a great range of actors with whom relationships often already exist (Porter, 2000).

Through these advantages, clusters can promote the market ramp-up of a technology sector. There is a consensus at both academic (Bleischwitz et al., 2008; Lambert & Schulte, 2021; Ogden & Nicholas, 2011) and political level (BMBF, 2019; BMBF, 2022) that the hydrogen market ramp-up can be efficiently designed with the help of clusters.

In addition to the general advantages of clusters, regional hydrogen clusters offer another specific advantage in the market ramp-up. Hydrogen has to be delivered as a physical good to the demand points, which requires a transport infrastructure and thus infrastructure investments. The regional proximity of many actors and, thus, a local concentration of demand volumes has the potential to significantly reduce the required infrastructure investments (Ogden & Nicholas, 2011).

The emergence of clusters for the use of grey hydrogen can, therefore, already be observed today; e.g., a hydrogen infrastructure network operated by Air Liquide in the Rhine-Ruhr region connects the chemical parks and refineries from Dortmund via Marl and Düsseldorf to Leverkusen (Lambert & Schulte, 2021).

The multiple benefits of clusters suggest that a cluster model is a viable option as part of a consistent market ramp-up strategy to rapidly implement the market ramp-up as well as to use limited public funds in the most efficient way (Ogden & Nicholas, 2011).

Identification of relevant clusters for the hydrogen market ramp-up

In order to accelerate the hydrogen market ramp-up through cluster formation, it is important to provide support to locations that offer good conditions for the development of clusters. The more prerequisites there are for the organic development of clusters, the more efficiently the formation of clusters can be promoted. For this purpose, identification criteria for the selection of locations for potential hydrogen clusters can be defined. Table 1 provides an overview of the relevant criteria.

Table 1: Identification criteria for future-proof hydrogen clusters

Supply	Availability of renewable electricity
	Environmental impacts (e.g., water balance)
Infrastructure	Existing transport infrastructure
	Perspective connection to transport infrastructure (e.g., European Hydrogen Backbone, “Kernnetz”)
Demand	Existing hydrogen demand
	"No-Regret" applications
Research & Education	Research and development (R&D)
	Skilled workers and training programs
	Knowledge spillover

The identification criteria for the selection of sites can be assigned to different categories:

- **Supply**: Since there is currently no nationwide transport infrastructure for hydrogen, even in the early stages of the market ramp-up, low-carbon hydrogen must be produced locally if needed. The production of green hydrogen mainly requires electricity and water. Therefore, locations with good availability of renewable electricity and a balanced water supply are particularly preferable.
- **Infrastructure:** Even if low-carbon hydrogen can be produced locally, a prospective connection to a hydrogen transport network represents a locational advantage. A connection can be used to cover rising hydrogen demand or demand peaks and to feed in possible surpluses. For example, plans in the European Hydrogen Backbone (EHB, 2023) and the core network (FNB, 2023) must be taken into account. In the case of low hydrogen demand and short distances, other means of transport, such as inland vessels, rail, or road transport, can also be used for the transport of hydrogen. Existing usable transport infrastructure, therefore, also has a strengthening effect on the respective location and its potential as a cluster location.
- **Demand**: Areas with an already existing (significant) demand for hydrogen can be used to build clusters. With existing demand, conventional hydrogen can often be substituted by low-carbon hydrogen without major technical hurdles ("drop-in" applications). In addition to the demand that exists today, some applications are designated as "no-regret". These are considered future-proof or even without alternatives, e.g., hydrogen use in the steel industry or heavy-duty transport (Agora Energiewende & AFRY, 2021; EWI, 2022).
- **Research & Education:** Overarching factors such as research and development (R&D) activities, skilled labor, education, training programs, and formal and informal knowledge spillovers can support cluster building at the location. These overarching

factors can create external economies of scale and thus generate locational advantages (EWI, 2023).

The more criteria a location or region fulfills, the faster a local market ramp-up can succeed. Currently, hydrogen is only used at industrial sites in Germany, especially in ammonia and methanol production and oil refining. Often, heavy and basic industries are already located in industrial clusters (EWI, 2021). The advantage of these hydrogen demand centers is that the existing hydrogen demand can provide a stable and already established sales market for the development of local production capacities. In addition, these demand centers are connected to natural gas transport networks and have a skilled workforce.

Status quo of hydrogen projects in Germany

From theory to reality. In order to check the status quo around hydrogen clustering, a presentation of publicly announced hydrogen projects is beneficial. Figure 1 shows publicly known power-to-X projects (as of February 2023), which were prepared for the data basis of the “H_2Bilanz” (E.ON & EWI 2023).

Operated electrolyzers are widely distributed across Germany (left map in Figure 1). Some of them are located close to industrial centers (e.g., 10 MW_{el} in Wesseling (REHFYNE, 2023)), others at coastal locations (e.g. 2.4 MW_{el} in Brunsbüttel -Wind2Gas Energy (W2G, 2023)). In total, only around 68 MW_{el} of electrolyzers were in operation in Germany by the end of February 2023 (E.ON & EWI 2023).

By contrast, a local concentration of planned projects can be observed by the end of 2030 (right map in Figure 1). The regions of the Central German Chemical Triangle (east), the Rhine-Ruhr metropolitan region (west), Lower Saxony with the Hamburg metropolitan region (north-west), as well as the Mecklenburg Baltic Sea coast (north-east) stand out with many planned projects. If the planned projects are implemented in these regions, hydrogen clusters could emerge. However, since most of the projects do not yet have a final investment decision (FID), it is difficult to foresee where hydrogen clusters will actually form.

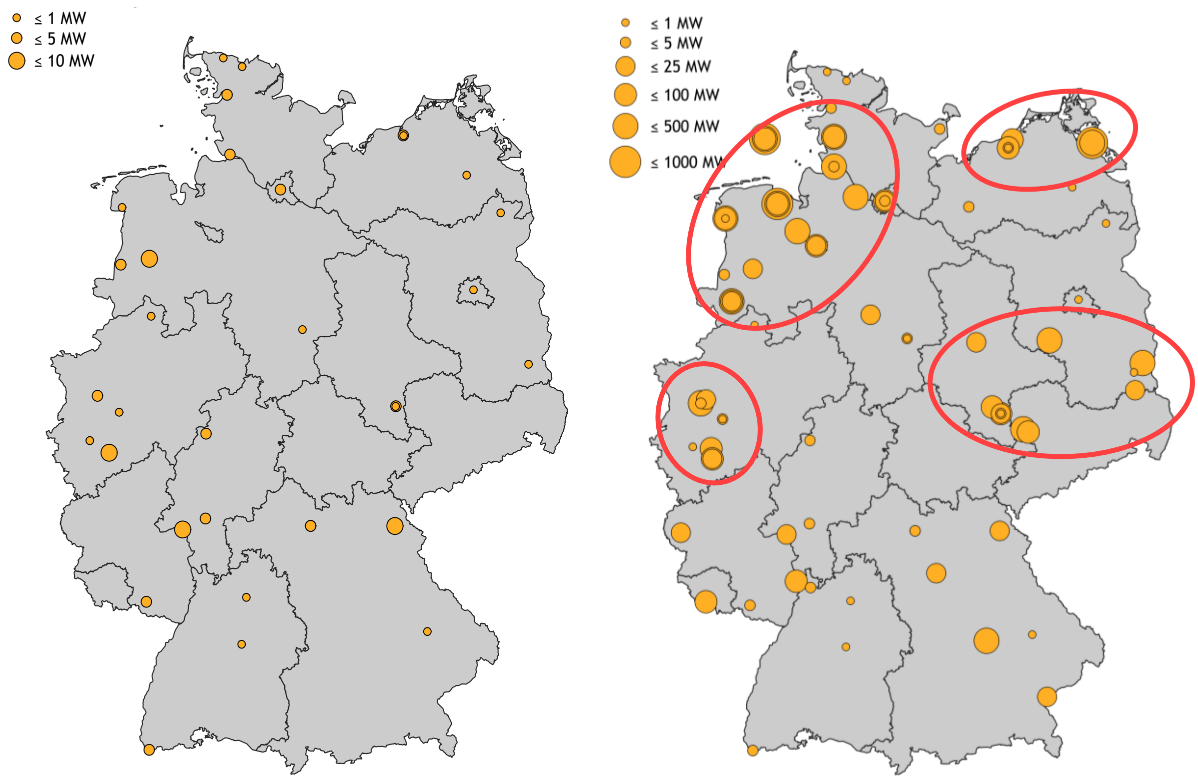

Figure 1: Power-to-X project maps for February 2023 (left) and 2030 (right). Regions with concentrations of projects are marked.

Source: E.ON (2023) and EWI (2023)

Outside these four regions, many individual electrolyzers are currently in operation or planned. For example, an 8.8 MW_{el} electrolyzer was commissioned in Wunsiedel (Bavaria) in 2022, which will supply end customers with truck trailers within a radius of 150-200 km and trucks and buses with green hydrogen at a public hydrogen filling station (Siemens, 2020; pv magazine, 2022). Projects such as the electrolyzer in Wunsiedel show that, in addition to hydrogen clusters, decentralized production for low demands such as filling stations can also make sense. Regions with only low future demand for low-carbon hydrogen and no prospects for connections to a hydrogen infrastructure can be supplied in this way.

Examples of planned hydrogen clusters in Germany

In order to promote the hydrogen market ramp-up, both political and private-sector actors have announced funding, projects, and cooperation. Some of these are already planned as clusters in the project structure or have a cluster structure through regional concentration of projects. Two examples are presented below:

Helmholtz Cluster Hydrogen HCH2 in the Rhenish Revier, Düren District, NRW

In 2020, the "Strukturstärkungsgesetz Kohleregionen "was passed for funding to establish a hydrogen cluster in the lignite mining area in the Rhineland. The funding amounts to 860 million euros until 2038. Funding is being provided both for the establishment of the Institute for Sustainable Hydrogen Economy (INW) at the Research Centre Jülich and for the development of the hydrogen cluster HCH2 itself (HCH2, 2023).

By the end of 2023, the INW is to conduct research in various stages of development, from basic research to operational systems, with 100 employees in four institute areas. By 2025, the number of employees is expected to grow to 400. Under the umbrella of the HCH2, funded demonstration projects are carried out in cooperation with partners from research and industry. There, the technologies developed are to be tested on an industrial scale (HCH2, 2023).

The Rhenish region offers good conditions as a regional hydrogen cluster: With "Zukunftscluster Wasserstoff ", which is funded as part of the "Clusters4Future" initiative of the Federal Ministry of Education and Research (BMBF), another center of excellence for research and development on hydrogen technologies is being established in the Aachen region (ZCW, 2023). The "Center for Sustainable Hydrogen Systems" at RWTH Aachen University offers hydrogen-specific courses to train future specialists (CSHS, 2023).

Furthermore, the neighboring chemical region in the greater Cologne area has the potential for complementarities along the value chain in addition to existing production, transport infrastructure, and demand for hydrogen (Schlund, Schulte & Sprenger, 2022; EWI, 2021).

Additionally, a medium-term connection of the Cologne region and the Rhineland area to the hydrogen core network is planned (FNB, 2023).

“Norddeutsches Reallabor” in the Greater Hamburg Area

The Norddeutsche Reallabor is being established in the Hamburg area as a cluster with expansion into the federal states of Schleswig-Holstein, Lower Saxony, and Mecklenburg-Western Pomerania. In this project, 50 partners from industry and research are investing a total of 405 million euros, including 55 million euros in funding from the Federal Ministry of Economics and Climate Protection (BMWK) as part of the 7th Energy Research Programme. The project focuses on the fully integrated production, transport, and use of hydrogen. Synergies with the electricity sector through grid-serving electrolysis operation and with the heat sector through waste heat utilization are to be considered. Specifically, the construction of electrolyzers at several locations is planned (e.g., the port of Hamburg and Brunsbüttel), as well as the development of new forms of use in the mobility and industrial sectors (e.g., hydrogen for copper production) (NRL, 2023).

The Norddeutsche Reallabor also offers potential for the development of a regional hydrogen cluster due to other factors: The greater Hamburg area already has significant renewable energy capacities in the form of onshore wind turbines and offers great potential for further expansion of onshore and offshore wind turbines.

The good conditions for green hydrogen are visible in additional existing electrolyzer projects, e.g., the "Hamburg Green Hydrogen Hub," with a planned capacity of 100 MW_{el} by 2026 (HGHH, 2023). In addition, the district of Dithmarschen near Brunsbüttel is home to "Westküste100", another BMWK funding project for researching and implementing the production, transport, and storage of hydrogen (WK100, 2023).

Finally, the region has high hydrogen demand potential due to the existing chemical industry in Hamburg and Dithmarschen (EWI, 2021) and should be connected to the hydrogen core network in the medium term (FNB, 2023).

These two examples of planned hydrogen clusters show regions where there is a concentration of local projects as well as good basic conditions for a sustainable hydrogen economy. This increases the likelihood of successfully forming hydrogen clusters in which the general advantages of a cluster described above can be realized.

Recommendations for action to build hydrogen clusters

Clusters bring various advantages. They can increase productivity, boost innovation, and make it easier to set up businesses. Organic growth of these clusters can accelerate the market ramp-up for a produced good or service. This is particularly true for the hydrogen market ramp-up. With regard to hydrogen, in addition to the general benefits, clusters can also reduce infrastructure costs. Thus, hydrogen clusters offer an opportunity specifically for the development of the hydrogen economy.

The analysis of the status quo of hydrogen projects in Germany shows a concentration of planned generation projects in four regions of Germany: Central German Chemical Triangle, Rhine-Ruhr Metropolitan Region, Lower Saxony & Hamburg Metropolitan Region, and Mecklenburg Baltic Sea Coast. In addition, a large number of decentralized individual projects are also planned. Many of these projects are publicly funded. The state funding currently appears very broadly based and without a clear focus. In addition, although many of the projects have been publicly announced, only few have a final investment decision, so there is uncertainty as to where projects will actually be realized.

In order to support the hydrogen market ramp-up through the establishment of clusters, the following approach is recommended:

1. **Identification**: In order to identify the potential for the successful establishment of a hydrogen cluster, an analysis of regions in Germany should be carried out. This can be based on the criteria defined above regarding supply, infrastructure, demand, and research education. Cluster potentials exist if several of these criteria are fulfilled by a location or region.

2. **Prioritization:** Based on the previously identified potentials of individual regions, a list of selected regions with particular cluster potential should be drawn up. In the next step, this prioritization could be supplemented by a weighting of the identification criteria.
3. **Focused support for the prioritized regions:** Promotion of the hydrogen market ramp-up should focus on selected regions with particularly high hydrogen cluster potential. In addition to financial resources, clear and regular political communication can help to attract private projects and investments. Furthermore, accompanying measures would have to be taken, such as accelerated approval procedures or the establishment of new and the expansion of existing personnel structures in responsible offices. In addition, the promotion of skilled workers by supporting education and training in the regions can counteract a shortage of skilled workers.

By implementing the measures presented, the probability of successfully establishing hydrogen clusters increases. This can accelerate the market ramp-up of hydrogen in Germany.

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