PRESS RELEASE

Achieving Climate Neutrality - Fraunhofer ISE Study Shows Regional Transformation Pathways for German Energy System

A new study by the Fraunhofer Institute for Solar Energy Systems ISE shows potential technological transformation paths towards climate neutrality by 2045 at the state level in Germany. The cross-sectoral energy system model "REMod" was used to quantify cost-optimized development paths for the energy, transport, industry and building sectors - including their necessary infrastructures. A variety of possible scenarios were considered. The study confirms the central role of electrification in a cost-efficient transformation, yet also the supplementary role of hydrogen for the industry, transport sector and power plants. The results indicate that a significant grid expansion is needed to transport electricity and hydrogen from northern Germany to the main consumption centers in western and southern Germany. In an energy system based largely on renewable energy, both energy generation and energy consumption must be made more flexible.

The transition of the energy system towards climate neutrality is in full swing. Concrete implementation plans on the regional level, e.g. for municipal district heating, are becoming increasingly important. The new study "Pathways to a Climate-Neutral Energy System: Federal States in the Transformation Process" addresses important current developments such as the changing energy demand, geopolitical uncertainties and infrastructure planning for power grid and hydrogen network expansions. The study uses spatially resolved optimizations to focus on the technical transformation at the state level. This was made possible by adding numerous extensions to the existing REMod energy system model, which mathematically simulates the German energy system (including energy imports) to calculate the most favorable transformation paths. The regionalized model shows possible pathways for ten regions in Germany, taking the required expansion of the electricity and hydrogen grids into account. The resulting cost-optimized regional transformation paths can now provide orientation for decision-making processes at the state level.

Four defining scenarios

Based on current social and political developments, the study examines four scenarios as possible paths to climate neutrality in 2045. In all of them, the German climate targets,

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including climate neutrality, are achieved by 2045 and the energy supply is always ensured throughout all consumption sectors.

The scenario "**Open Technology**" describes the cost-optimized transformation path of the energy system without considering additional, fixed boundary conditions. A high degree of freedom with regard to the selection of available technologies is assumed.
The scenario "**Efficiency**" is based on stricter climate targets: By 2045, CO_2-emissions must be reduced by 1000 million-tonnes. At the same time, a faster expansion of renewable installations (particularly solar and wind) is assumed possible. Also, energy demand decreases due to higher efficiencies and falling consumption (sufficiency).
In the scenario "**Persistence**", existing technologies such as vehicles with combustion engines or fossil-fuel based heating systems are retained longer. The climate-friendly conversion of industry is also delayed.
In the scenario "**Robust**", geopolitical uncertainties and climate change are taken into account. For example, the availability of photovoltaic and battery storage systems is assumed to be reduced due to geopolitical reasons, delaying the potential expansion in Germany.

Direct electrification central to the decarbonization of all sectors

The study results show that, when technically possible, direct electrification is the most cost-effective option for the overall system: Thus, heat pumps will be the dominant heating technology in 2045. Battery-electric vehicles will be used almost exclusively in private transportation. The degree of electrification in industry will rise to around 70 percent. Due to the high level of electricity use in the consumer sectors, demand for electricity is expected to double in all German federal states by 2045. In addition, the wind-rich states of Schleswig-Holstein, Lower Saxony and Mecklenburg-West Pomerania will experience the development of a major new electricity consumer in the form of domestic hydrogen electrolysis. Depending on the scenario, electricity consumption of between 1,150 and 1,650 TWh can be expected in 2045.

Northern Germany shall supply one third of the primary energy in 2045 and become a supplier of hydrogen

Wind energy and photovoltaics are proving to be the central pillars of the energy transition, which is why onshore wind energy is to expand even in supposedly low-wind states. In the open-technology scenario, today's installed onshore capacity shall double by 2030 and reach around 290 gigawatts by 2045. The installed photovoltaic capacity increases to up to 420 GW by 2045.
For 2045, the study shows that Lower Saxony, Schleswig-Holstein and Mecklenburg-West Pomerania will provide a third of Germany's primary energy due to their high wind power potential and that power-to-x technologies will greatly expand. Electrolysis will play a central role in flexible electricity consumption, which is why a large proportion of

the expected 65 GW of electrolysis capacity will be installed in the north. In contrast, more battery storage systems will be installed in those states dominated by photovoltaics.
For optimal energy distribution between the north and the industrially strong federal states of North Rhine-Westphalia, Baden-Württemberg and Bavaria, the expansion of the electricity grid is key alongside the hydrogen infrastructure, especially the north-south and north-west connections. Storage capacities of at least 130 TWh are required for hydrogen, which is primarily needed for high-temperature processes and for material use in industry.
In order to compensate for the large regional differences in generation and demand, the flexibilization of electricity demand plays a major role in all scenarios. Flexible gas and hydrogen power plants are used in all states to stabilize the grid. Electric vehicles and stationary batteries are used as short-term battery storage.

Accelerated technology expansion and energy efficiency can save transformation costs

The differential costs for the open technology transformation path compared to simply continuing with the current energy system amount to an average of around € 52 billion per year over the next 25 years. This corresponds to around 1.2 percent of today's gross domestic product or - to use a different benchmark - around half of the turnover of the 2023 Christmas shopping season. The average CO_2 avoidance costs for the years 2024 to 2045 in this scenario are just under € 220 per tonne of CO_2. In the "Efficiency" scenario, the transformation costs are significantly lower at just under €90 per tonne of CO_2, due to the lower energy demand. In contrast, the highest transformation costs of just under €320 per tonne of CO_2 result when sticking to conventional technologies and delaying the expansion of renewables as described in the "Persistence" scenario. These costs arise particularly due to the higher import volumes of synthetic energy carriers and the increased use of negative emission technologies necessary to achieve the climate targets.

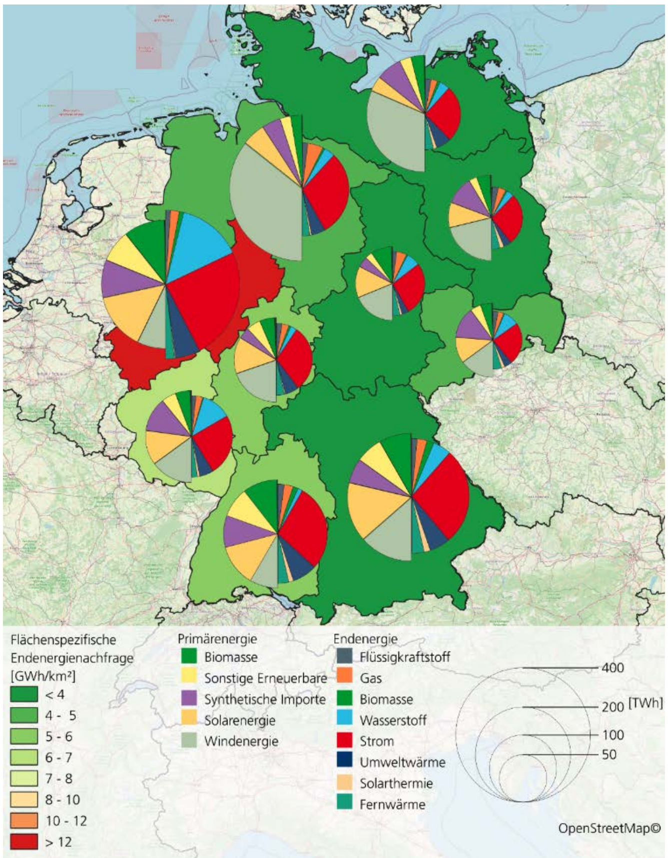

Fig. 1 Primary energy supply and final energy demand of the individual states in 2045 in the "open technology" scenario. © Fraunhofer ISE

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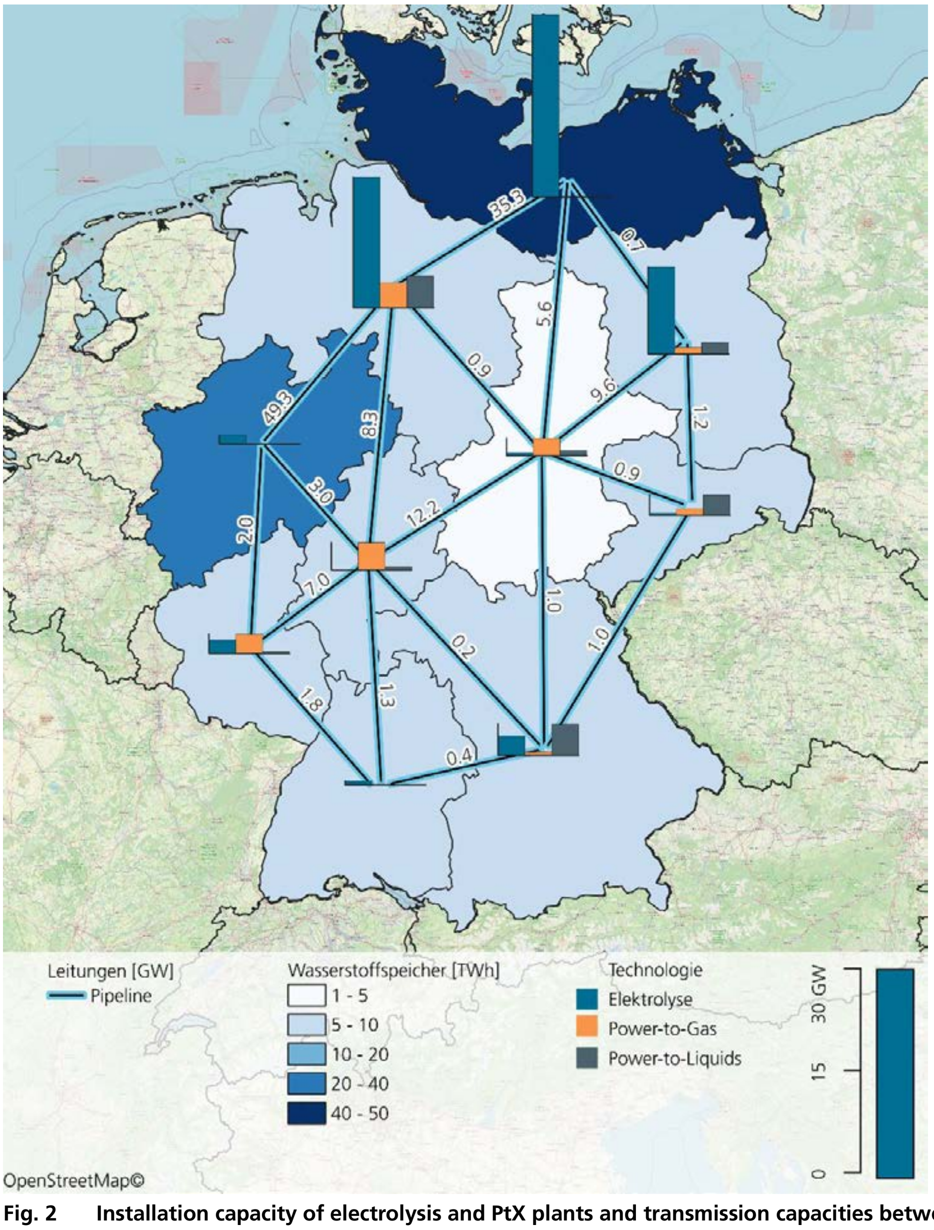

Fig. 2 Installation capacity of electrolysis and PtX plants and transmission capacities between the states in the "open technology" scenario in 2045 © Fraunhofer ISE

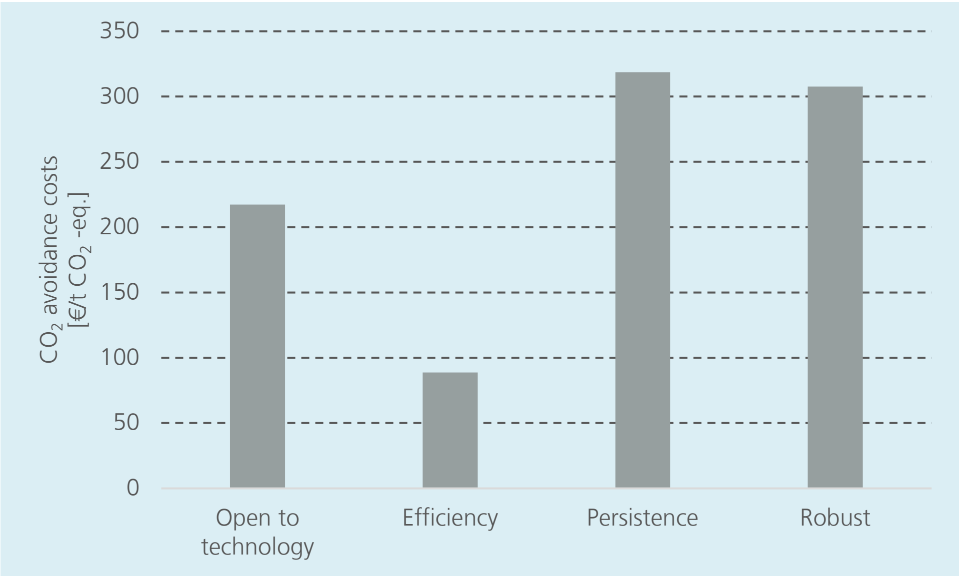

Fig. 3 Average CO_2 avoidance costs for the years 2024 to 2045 for the four scenarios examined. © Fraunhofer ISE