

Germany's green transition regains momentum

The country aims to be climate neutral by 2045.

In the years leading up to and following Germany's September 2010 law in support of the *Energiewende*—the transition to renewable energy—the country was a world leader in efforts to counter climate change. It made great strides in creating a market for photovoltaics, increasing electricity production from renewable sources, passing legislation to make new construction more energy efficient, and getting the public on board. But by the latter 2010s, the transition had stalled: Deployment of wind and solar farms had slowed, and progress in the industrial, heating, and transportation sectors was at a standstill or even backsliding.

Now a combination of domestic and international developments has reinvigorated the *Energiewende* in Germany. Extreme weather events are on the rise worldwide, including floods that killed 196 people in western Germany last summer. Statements by the Intergovernmental Panel on Climate Change (IPCC) express increasing urgency. In a 4 April press release accompanying the publication of the final section of its sixth assessment report, for example, Jim Skea, cochair of the IPCC's Working Group III, which focuses on climate change mitigation, said, "It's now or never, if we want to limit global warming to 1.5 °C. Without immediate and deep emissions reductions across all sectors, it will be impossible."

Germany's new government, elected last fall, has ambitious climate goals. It has pledged €200 billion (\$220 billion) through 2026 toward infrastructure for decarbonization and climate protection purposes. In 2019 the country voted to phase out coal-fired power generation by 2038; now the government is shooting for 2030. The European Union aims for

net-zero greenhouse gas emissions, or climate neutrality, by 2050; Germany's new government affirms the aim set last year to best that by five years. "The old government was ramping up too," says Ferdi Schüth, a chemist at the Max Planck Institute für Kohlenforschung in Mülheim an der Ruhr who has long worked on energy issues. "But the mindset of the new government is more aggressive in terms of renewables."

And although Russia's invasion of Ukraine focuses attention on fears of a wider war and the immediate needs of refugees, it also highlights the precariousness of relying on coal, oil, and gas imports from Russia and the need for energy independence. Without gas from Russia, "we don't know if we can heat buildings and fuel industries next winter," says Cyril Stephanos, who heads Energy Systems of the Future, an initiative to support the energy transition run jointly by the German Academies of Sciences.

In the short term, Stephanos says, Germany will depend more on lignite coal—it's the only viable domestic substitute for gas in the electricity sector. Nuclear power is in the final stages of being phased out in Germany, and renewables can't be ramped up quickly enough. But longer term, he says, Russia's war in Ukraine will help accelerate climate protection. "Switching from fossil fuels to renewables will make us more independent."

"In principle, we have the necessary tools to decarbonize," Stephanos says. "Over the next decade, we need to develop technologies for hydrogen transport and storage." Other challenges include diversifying energy imports, overcoming public resistance to wind farms, persuading the public to make lifestyle changes, and

implementing decarbonization equitably, without imposing undue burdens on lower-income people.

Green electrons

The transition to green energy will quadruple Germany's demand for renewable energy, according to estimates by the sister think tanks Agora Energiewende and Agora Industry in their 2021 publication *12 Insights on Hydrogen*. Using renewable energy for electric vehicles, electric heat pumps, and hydrogen production will drive that increase. Germany aims to triple the number of wind farms, increasing their total coverage from 0.9% to 2% of the country's land area. Also planned are more off-shore wind farms and photovoltaic fields. The share of renewable energy in electricity consumption grew steadily from around 6% in 2000 to 46% in 2020, says Ortwin Renn, a social scientist and scientific director of the Institute for Advanced Sustainability Studies in Potsdam. In 2021, it slipped to about 41%.

Still, Germany cannot meet its own electricity demands with domestic renewable energy. "We could import solar energy from Greece or North Africa, for example," says Renn. "We need to expand and modernize the European grid for that." And, he stresses, the war in Ukraine has intensified the need to diversify energy. The federal minister for economic affairs and climate action, Robert Habeck, "is going all over the world looking for liquefied natural gas." Progress on the *Energiewende*, Renn says, "depends on how things evolve in the coming months."

The *Energiewende* has wide public support—about 80%—"until someone wants to put a wind turbine near your house," says Renn. "We need to get over NIMBY [not in my backyard]." It would



OFF-SHORE WIND FARMS typically produce more energy than land-based ones, but more of both are needed to ramp up renewables in Germany. (Photo by Martina Nolte, licensed under <https://creativecommons.org/licenses/by-sa/3.0/de/legalcode>.)

	Industry 	Transport 	Power sector 	Buildings 
No regret	<ul style="list-style-type: none"> ► Reaction agents (Direct Reduced Iron steel) ► Feedstock (ammonia, chemicals) 	<ul style="list-style-type: none"> ► Long-haul aviation ► Maritime shipping 	<ul style="list-style-type: none"> ► Renewable energy backup, depending on wind and solar share and seasonal demand structure 	<ul style="list-style-type: none"> ► Heating grids (residual heat load *)
Controversial	<ul style="list-style-type: none"> ► High-temperature heat 	<ul style="list-style-type: none"> ► Trucks and buses ** ► Short-haul aviation and shipping ► Trains *** 	<ul style="list-style-type: none"> ► Absolute size of need given other flexibility and storage options 	
Bad idea	<ul style="list-style-type: none"> ► Low-temperature heat 	<ul style="list-style-type: none"> ► Cars ► Light-duty vehicles 		<ul style="list-style-type: none"> ► Building-level heating

* After using renewable energy and ambient and waste heat as much as possible. Especially relevant for large existing district heating systems with high flow temperatures. Note that according to the United Nations Framework Convention on Climate Change common report format, district heating is classified as being part of the power sector.

** Production is currently more advanced for electric than for hydrogen heavy-duty vehicles and buses. Heavy-duty hydrogen vehicles to be deployed at this point in time only in locations with synergies (ports, industry clusters).

*** Depending on distance, frequency, and energy supply options.

help, he says, for the public to be involved in decisions about where wind farms are placed and for individuals or municipalities to reap benefits from the electricity the wind turbines produce. "People should develop an emotional attachment to the turbines and their contributions to decarbonization."

The price of carbon emissions needs to be sufficiently high to increase the attractiveness and competitiveness of renewables, says Schüth. "More renewables is number one. Everything hinges on that."

Intersecting energy sectors

Fossil fuels for industry, transportation, and heat together make up roughly 80% of Germany's energy consumption—just 20% is from electricity. Long-distance trucking, maritime shipping, and aviation are among the most difficult activities to power with renewable energy. Scenarios such as electric tracks for trucks are being floated and tested. But the greening of trucking and aviation will have to rely on synthetic fuels based on green hydrogen when they become available at an industrial scale and competitive cost. Emissions may also be lowered with carbon capture and storage.

Significant progress, however, has been made with electric personal vehicles (see PHYSICS TODAY, April 2022, page 22). "Soon they'll be cheaper than combustion cars in terms of total cost of car ownership," predicts Frank-Detlef Drake, who heads research and technology at the electric utility E.ON SE in Essen. Germany's new government aims to increase the number of electric vehicles on

GREEN HYDROGEN, produced with renewable energy, complements green electrons, but it should be reserved for "no-regret" uses. This table outlines uses for green hydrogen as recommended by the think tanks Agora Energiewende and Agora Industry. (Adapted from Agora Energiewende, Agora Industry, *12 Insights on Hydrogen*, 2021, fig. 4.)

the road from fewer than 1 million today to 15 million in 2030. But for their widespread adoption, a convenient network of charging stations is needed. Such a network could be built with money from the government's €200 billion infrastructure pot.

Germany aims for half of all home and business heating to be climate neutral by 2030. That goal is in line with Agora's estimate of Europe needing to reduce its consumption of natural gas in buildings by 42% for it to stay on track to limit warming to 1.5 °C above preindustrial levels. And to achieve Germany's goal of climate neutrality by 2045, Agora calculates that 1.75% of buildings must be retrofitted annually to improve energy efficiency. The country has for years had a retrofit goal of 2%. Currently, only one out of every hundred buildings is renovated annually to improve energy efficiency, according to Germany's Ministry for Economic Affairs and Climate Action.

Decarbonizing the heat sector is complicated. For new construction, "we have good standards," says Drake. "The challenge is existing buildings. They are tough." Most of the country's buildings are heated with natural gas.

Renovating existing buildings involves insulating them and converting their heating systems to electric heat pumps, which work like reverse refrigerators, sucking heat from the outside air or ground and

depositing it in a water or air heating system. In densely populated areas, centralized district heating can be installed or converted to use green energy.

Another possibility for heating would be to mix green hydrogen with natural gas in existing gas pipelines. The idea, Renn explains, would be to produce hydrogen gas with renewable energy. About 20% hydrogen could be used without corroding the pipelines, experts estimate. "It's counterintuitive, since you make clean hydrogen and then contaminate it, but financially it could be a good idea, at least for a while. It seems odd to let our existing infrastructure rot."

But Barbara Saerbeck, a senior associate at Agora Energiewende, notes that neither natural gas boilers nor hydrogen-powered heating systems provide climate-neutral and efficient use of green energy. "Relying on a still rare and expensive energy carrier such as hydrogen for heating buildings is not a viable path to climate neutrality," she says. "It's crucial to switch to green-energy-based fuel in the power sector, district heating, and buildings." She also notes a lack of skilled workers. "For years, people have built fossil-fuel heating systems. We need to train people to work with electric heat pumps." With a concerted effort and clear legal requirements, she adds, a switch to heat pumps and insulated buildings is possible "without overburdening any-

one in terms of planning or finances."

Insulating walls and windows and converting to heat pumps is expensive. About half of residents in Germany are tenants, and they may hesitate or be unable to invest in properties they don't own. Landlords, meanwhile, may choose not to invest in renovations that lower their tenants' utilities bills. The question of who would pay is tricky.

The greening of mobility also introduces equity issues. On a day-to-day level, rising gas prices—and their far-reaching consequences—sting low-income people more than high-income people. And buying an electric car, despite government subsidies, is still out of financial reach for many people. Recently the German government promised to give €300 to all households to help with surging gas costs, but such handouts are a Band-Aid, not a real solution to inequities associated with the Energiewende, says Renn.

Green molecules

Major challenges in the transition to a green economy are industry—the manufacture of steel and chemicals in particular rely heavily on fossil fuels—and long-haul aviation, trucking, and maritime shipping. Those are areas where hydrogen and hydrogen-based fuels could play a crucial role. Another area would be as backup power generation for intermittent solar and wind sources. In *12 Insights on Hydrogen*, Agora notes that hydrogen and hydrogen-based fuels are anticipated to supply 14–25% of global energy demand; the percentage in Germany is similar.

Hydrogen contributes to the energy transition only if it's produced with renewable energy. The cleanest approach is water electrolysis powered by green electricity. Hydrogen can be transported as a liquid, as a gas, or in a chemical form such as ammonia. Experts agree that Germany will have to import hydrogen because the domestic wind and solar electricity sources are not sufficient for both direct electrification and electrolysis. To that end, the German government is talking with Australia and countries in Africa and South America that have abundant low-cost solar and wind energy.

A bottleneck is transportation from German ports to points of use, says Robert Schlögl, a chemist at the Max Planck Institute for Chemical Energy Conver-

sion in Mülheim an der Ruhr. He heads a collaboration in Germany that was awarded €135 million last June to study hydrogen transport and other aspects of green hydrogen for energy, including safety, standardization, storage, conversion to and from ammonia, and more.

In a separate collaboration, Schlögl and colleagues are working on hydrogenating carbon dioxide to make methanol for use in heavy industry. The team is testing its synthetic fuels with steel and cement demonstration projects. Germany's steel industry emits 20 million tons of CO₂ annually, says Schlögl. "If we can produce enough methanol with green hydrogen, we can shrink those emissions by 90%." Methanol could also be used to fuel ships, airplanes, and cars, possibly providing "a viable alternative to electric cars," he says.

Agora, for its part, favors other approaches for personal cars, and says hydrogen should be used for applications where better alternatives are unavailable (see the "no-regret" row in the chart on page 24). But Schlögl says that while the main use will be heavy industry, he is "open to all end uses."

Accelerated energy sovereignty

On 24 March, a month into the war in Ukraine, Agora Energiewende published *Regaining Europe's Energy Sovereignty*. Relying on new internal studies, the report is meant to advise European Union leaders as they hasten to wean their countries from Russian fossil-gas imports, while also helping to achieve climate targets. With 15 recommended actions and €100 billion in new funding, the report says, Europe can achieve energy sovereignty within five years.

A press release accompanying the report says that "a concerted crisis effort" to improve energy efficiency could enable replacement of 80% of today's Russian gas imports by 2027; the addition of liquefied natural gas could bring that up to 100%. Those efficiencies could be accomplished, it says, by reducing fossil-gas use by 480 TW hours in buildings and 223 TW hours in industry, plus scaling up production of renewable energy by 500 TW hours. Governments "need to ban the installation of new gas boilers and increase financial support to unleash a heat pump revolution," Matthias Buck, Agora Energiewende director for Europe, says in the press release. And Eu-

rope "must scale renewable energies as fast as possible, pulling all stops."

Christopher Hebling is the director of the hydrogen technologies division at the Fraunhofer Institute for Solar Energy Systems in Freiburg. "With each IPCC report, it seems we have lost the game already," he says. "Everyone agrees that climate change is humanity's biggest challenge." But, he adds, people like to go on vacation, they like to drive their own car, and they want to live in bigger apartments. "Money is not the missing link. It's governance and buy-in. The coming years are the most decisive for humanity." Germany's national target of 2045 for climate neutrality is unrealistic, he says. "But it sharpens the visions and nails down the targets."

Individuals will have to change their behavior to reach climate goals. "We need to be transparent about that," says Schüth. The goals for the Energiewende in Germany and beyond are ambitious, he says. In seeking solutions, "we tend to extrapolate linearly. But we should be ready to work for radical change."

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