

Smart Electric Power Alliance

Insight Brief: Key Learnings from the Executive Fact-Finding Mission to Germany

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SEPA Insight Brief: Key Learnings from Executive Fact-Finding Mission to Germany

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Executive Summary

This October, a delegation of 15 U.S. utility and technology company executives traveled to Berlin, Germany to meet with industry leaders and government officials. This trip, referred to as an Executive Fact-Finding Mission, was the 15th such trip organized by the Smart Electric Power Alliance (SEPA) to provide delegates with a look into international renewable energy progress. During the week in Germany, the U.S. team visited the German Association of Energy and Water Industries (BDEW), the Federal Ministry for Economic Affairs and Climate Action of Germany (BMWK), Schneider Electric, 50 Hertz, Salzgitter AG, and Vattenfall to learn more about Germany's energy transition, known as *Energiewende*. Discussions focused on Germany's commitment to a low-carbon economy and its approaches to achieving its ambitious renewable energy goals. This brief distills SEPA's first-hand insights about Germany's renewable energy transition:

1. **Germany's Energiewende, supported by national policy, has accelerated electricity sector decarbonization but has come with higher customer costs and potential drawbacks**, such as reduced flexibility and innovation due to technology lock-in. In contrast, the United States, lacking a cohesive national climate or energy policy, relies more on state-led initiatives and market-driven approaches.
2. **Germany's grid-centric approach, backed by public support, often emphasizes enabling infrastructure development over customer engagement**, addressing some challenges while creating others. In contrast, thanks to earlier AMI deployment, U.S. utilities tend to have a more customer-centric approach to the renewable energy transition.
3. **Sector coupling—an integrated approach to energy planning and consumption across multiple sectors, including electricity, heating and cooling, buildings, transportation, and industry—will be key to the energy transition in both Germany and the United States.** Unlike the U.S., Germany has significantly focused on hydrogen as an energy carrier, with plans to develop extensive hydrogen infrastructure in the coming years to support industrial use of the emerging fuel.
4. **While the German population remains supportive, rising costs could threaten public acceptance of the energy transition in the future.** German customers currently pay around 40 cents per kilowatt-hour for electricity, a burden exacerbated by the country's shift away from Russian natural gas following the 2022 invasion of Ukraine. In contrast, public support for climate change mitigation in the U.S. is lower, and American customers are less tolerant of price increases to accelerate the energy transition.
5. **Transmission expansion, interconnection queue management, and cost allocation for storage, wind, and solar projects are critical challenges for German and U.S. transmission system operators.** Despite differences in wholesale market designs, grid operators in both countries face remarkably similar difficulties. However, the U.S. is slightly ahead of Germany in exploring innovative approaches, such as flexible interconnection agreements and cluster studies.

Introduction

For the last 15 years, SEPA and a team of utility and renewable energy executives have traveled abroad to bring some of the latest renewable energy developments home to the U.S. This year's destination was Berlin, Germany. Germany's leadership on sector coupling and clean transmission expansion and their grid-centric approach provided ample learning opportunities for our U.S. group. The goal of SEPA's fact-finding mission to Berlin was to explore how Germany is addressing its energy transition and to draw insights that could inform the U.S. decarbonization strategy. Meetings with key stakeholders provided a holistic view of the Energiewende's challenges and successes, particularly regarding infrastructure development, public support, and the role of hydrogen (H2) and sector coupling. Germany's energy transition offers positive and cautionary lessons for the U.S. energy market. Over the course of five days, SEPA's delegates met with German leaders who are driving the energy transition—including trade associations, policymakers, transmission system operators, distribution system operators, and clean steel companies. The atmosphere during these meetings was energetic and open, with leaders from the U.S. and Germany sharing recent experiences, challenges, and forecasts for the future.

Two major driving forces clearly defined the German perspective on the energy transition: long-standing public sentiment that climate change is an existential challenge requiring urgent action and the energy crisis spurred by Russia's invasion of Ukraine, which has accelerated efforts to move away from Russian natural gas and emphasized the importance of energy security alongside a commitment to renewable energy.

Background: Germany's Energy Context

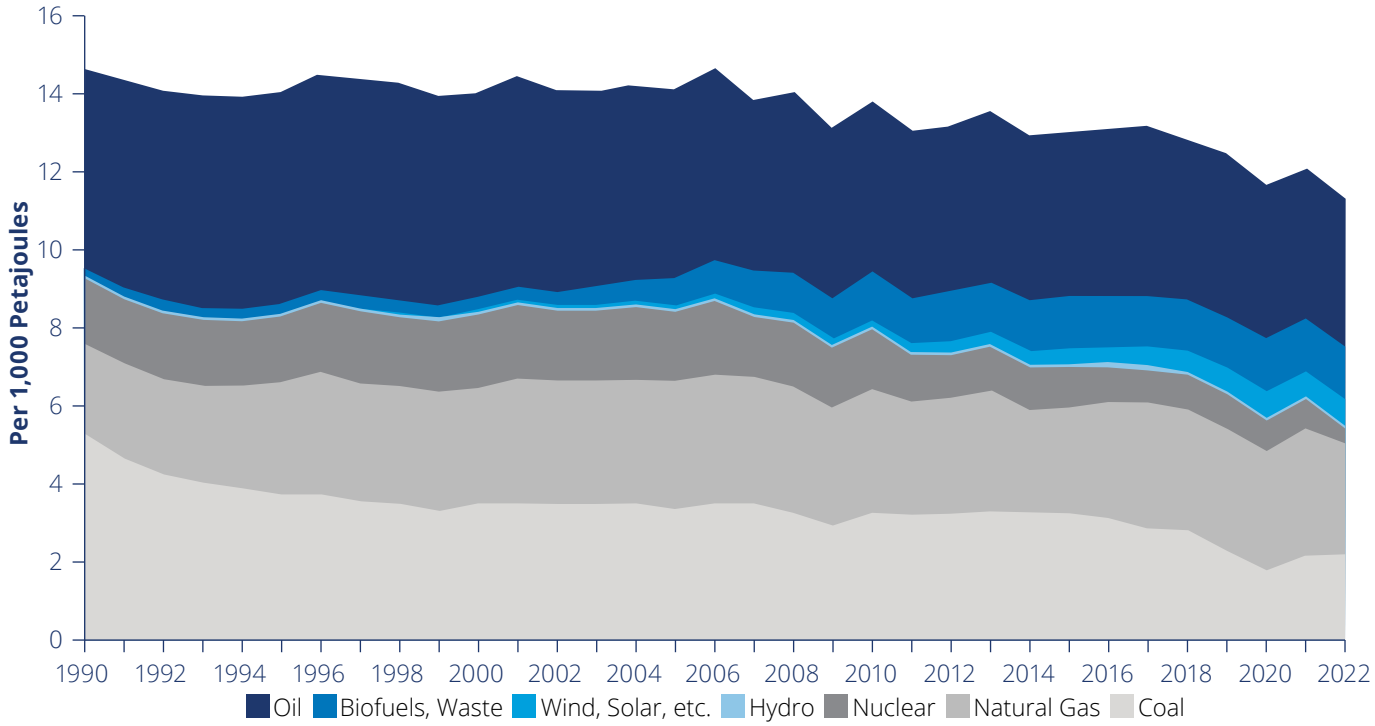
Over the past 20 years, Germany has made significant progress in lowering the carbon intensity of its energy mix. Central to these efforts is the Energiewende, Germany's national strategy aimed at achieving climate neutrality while maintaining energy security and economic viability. The five pillars driving this strategy—renewable energy, hydrogen, natural gas, grid expansion, storage, and flexibility—support a comprehensive approach to decarbonization.

The roots of the Energiewende date back to the early 2000s, when Germany first adopted a comprehensive renewable energy law, the Renewable Energy Sources Act (EEG), which incentivized the expansion of renewable energy, particularly wind and solar power, through feed-in tariffs. In 2010, the Energiewende was officially articulated as a comprehensive framework that not only aimed at reducing greenhouse gas emissions but also sought to ensure that the country could maintain a secure and competitive energy supply during the transition. Following the 2011 Fukushima disaster, Germany accelerated its nuclear phase-out plan, committing to shutting down all of its nuclear power plants by 2022. Germany laid out its Energiewende commitment in the 2021 Climate Act, which aims to reduce emissions by 65 percent of 1990 levels by 2030 and achieve carbon neutrality by 2045. Germany describes Energiewende as a renewable energy triangle: making progress towards climate neutrality, strengthening the security of supply, and ensuring economic viability and affordability.

Since the launch of the Energiewende, Germany has made significant strides in transforming its energy landscape. As of 2023, Germany had reduced its energy consumption roughly 25% below 1990 levels. Within Germany's energy supply, coal, oil, and nuclear decreased 57%, 25%, and 77%, respectively, with nuclear completely phasing out as the last three nuclear plants closed in April of 2023. To compensate, the energy supply from natural gas, biofuels, and renewables has increased (Figure 1).

The Russian invasion of Ukraine in 2022 resulted in an EU-wide energy crisis due to the heavy reliance on Russian-supplied natural gas. On average, EU countries covered 40% of their natural gas needs through Russian imports, with Germany being among the most exposed, sourcing 55% of its gas from Russia. In May 2022 the

Figure 1. Total Energy Supply by Source in Germany Between 1990-2022



Source: ScottMadden (n.d.). Recreated by SEPA.

European Commission launched the REpOwerEU plan to reduce energy consumption, diversify energy supplies, and produce more renewable energy across the entire region. Germany followed the example of the rest of the EU, decreasing its natural gas consumption by 18% at its peak (between August 2022 and March 2024) and sustaining a 10% natural gas reduction.

Between 2022 and 2024, Germany built seven liquified natural gas (LNG) terminals to enhance its capacity to import natural gas in various forms and from a broader range of countries. The nation also initiated 150 new renewable energy infrastructure projects, including installing 96 GW of solar, 40 GW of wind, and over five million heat pumps, while also focusing on growing the national hydrogen industry. Through these efforts, Germany was able to end its dependence on Russian-imported natural gas within nine months of the Russian invasion of Ukraine.

Key Findings from the Mission

The following section highlights insights from SEPA's Executive Fact-Finding Mission to Germany. These findings reflect Germany's ongoing renewable energy transition, the challenges and successes experienced along the way, and the strategies being implemented to meet the country's ambitious climate goals. The key takeaways provide lessons for U.S. stakeholders navigating their path toward a low-carbon future.

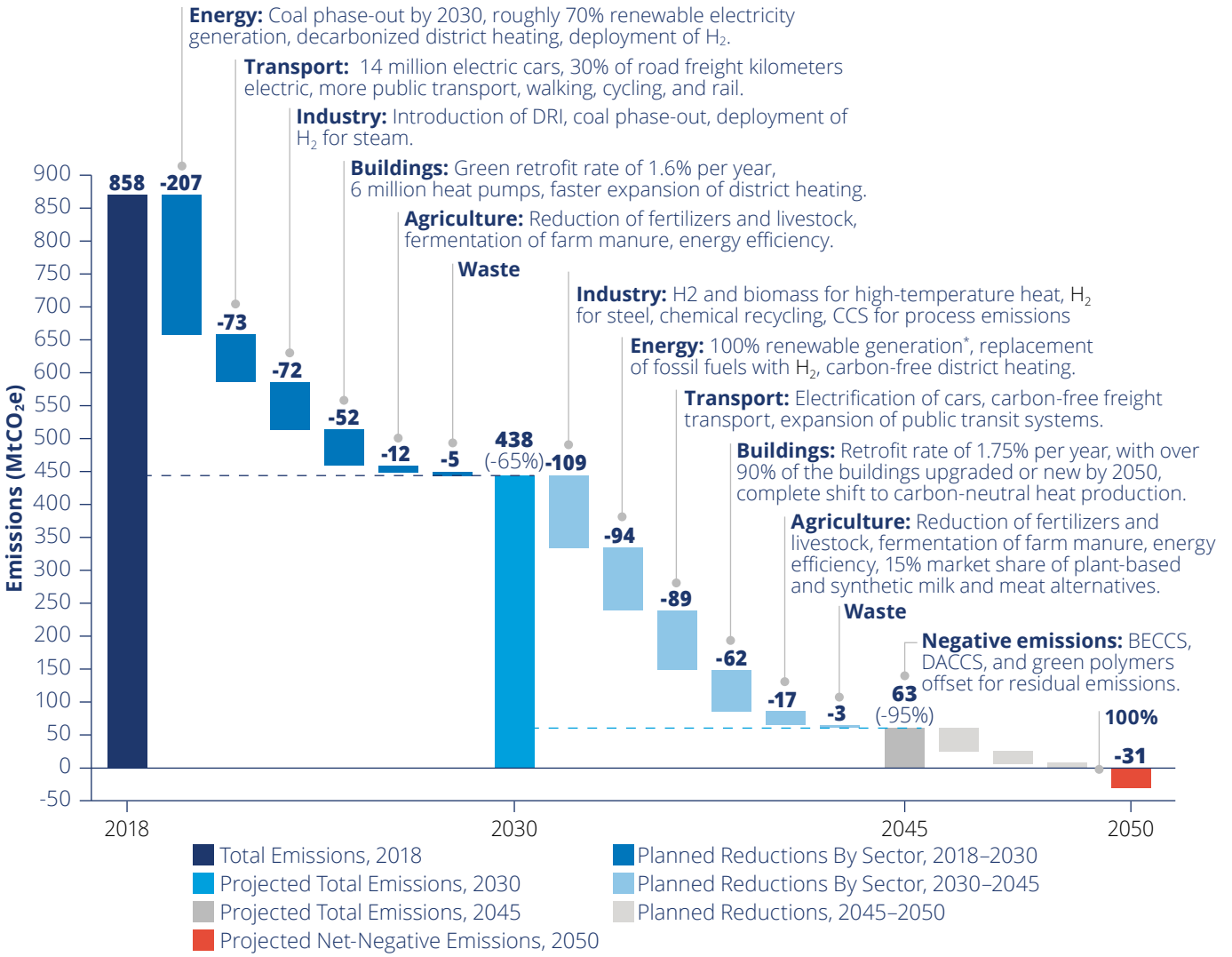
Key Finding 1: National Direction & Commitment Yield Significant Benefits

Energiewende's national direction and commitment yield significant benefits but also introduce complex challenges and trade-offs that impact policy, technology, and cost.

Benefits

The Energiewende has enabled Germany to deploy renewable energy sources successfully at an accelerated pace. This has included achieving over 60% of annual consumption derived from renewables while maintaining an incredibly stable grid with an average customer outage of less than 12 minutes annually. By setting clear goals, the German government ensures policy alignment across sectors. These decarbonization objectives are designed to start with the energy sector but are not limited to it and further expand into other sectors, such as industry, transportation, and agriculture (Figure 2).

Figure 2. Germany's Measures to Reduce Greenhouse Gas Emissions (2018 - 2045), in Million Metric Tons of CO_2 Equivalent ($MtCO_2e$)



Source: Prognos AG, Öko-Institut e.V., & Wuppertal Institut für Klima, Umwelt, Energie gGmbH. (2021). Towards a climate-neutral Germany by 2045: How Germany can reach its climate targets before 2050 (Executive Summary). Recreated by SEPA.

*This includes electricity generated from renewably generated hydrogen.

** This figure merely extrapolates the trend after 2045; further emission reductions are possible.

Public Support for Energiewende

Germany's renewable energy strategy has been characterized by a 'grid-centric' approach, emphasizing rapid infrastructure development and integration of renewables, with less immediate focus on consumer preferences and cost implications. In contrast, the United States has adopted a customer-centric model, which prioritizes affordability and consumer choice, often leading to a more gradual transition. This distinction is evident in Germany's ambitious targets and substantial investments in grid expansion, compared to the U.S.'s emphasis on balancing renewable integration with cost considerations and consumer demand.

Strong public support for the country's climate goals, with over 75% of the population in support of the Energiewende, makes Germany's grid-centric approach possible. The German public views Energiewende as a national imperative, which has allowed Germany to focus primarily on large-scale infrastructure solutions—like expanding the transmission grid and integrating renewable energy—rather than smaller-scale customer-side solutions. BDEW and BMWK described the public's acceptance of high costs related to the energy transition, though they acknowledged potential support could wane in the future. The population responded to the government's call to conserve gas during the energy crisis and achieved an 18% reduction during the crux of the gas crisis. Germany has sustained a 10% reduction ever since, simply through behavioral changes.

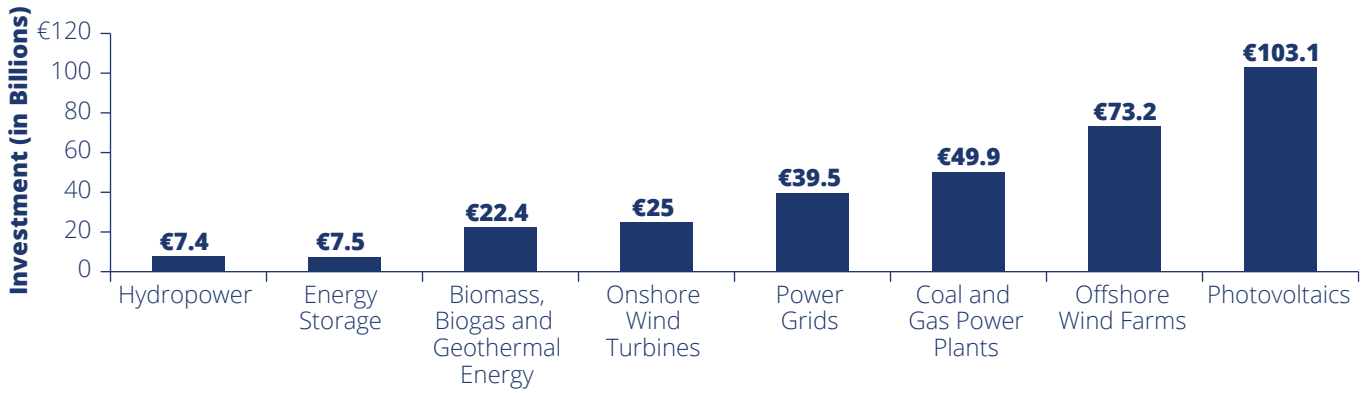
Challenges

Despite the momentum, Energiewende comes with a substantial price tag. The rapid build-out of renewable infrastructure and underground transmission lines has raised costs by billions of euros, which could eventually strain public support. By 2031, Germany is expected to have spent 103.1 billion euros on solar energy alone (Figure 3). There is also a risk of technology lock-in, especially with hydrogen, where significant investments are being made despite unresolved questions about long-term affordability and scalability. As our group and BDEW discussed, hydrogen infrastructure development is still in its early stages, with full deployment not expected until at least 2038. Notwithstanding, the German government and industry are committed to hydrogen as a critical storage and sector-coupling technology.

Considerations for the U.S.

Unlike Germany, the U.S. energy transition operates primarily in a decentralized, market-driven system. Adding to the complexity, the U.S. has a patchwork of regulatory environments with state and local level jurisdictions involved in many aspects of grid planning and infrastructure investment decisions. This provides more flexibility and room for customer innovation, such as rooftop solar, demand response programs, and behind-the-meter customer storage, but has resulted in slower and inconsistent adoption rates and policies across states. The inconsistent policies across states can be particularly challenging for companies that operate in many states and are required to navigate complex diversity of policy, law, economics, and customer demand. Consistency in energy policy across space and time enables the private sector to commit to longer-term, larger-scale investments in the renewable energy transition, a key advantage in Germany's coordinated approach. In contrast, companies in the U.S. face a fragmented landscape of shifting federal priorities, state-specific regulations, and diverse market structures, making it more challenging to plan and invest with confidence.

Figure 3. Predicted Investments in New Power Plants, Energy Storage, and the Grid in Germany until 2031 as Part of the Energiewende



Source: Renew Economy (July 30, 2013). Energiewende: The German energy transformation explained. Recreated by SEPA.

Key Finding 2: Grid-Centric vs. Customer-Centric Approach

Grid-Centric Approach

Germany's grid-centric approach is evident in its significant investments in transmission infrastructure to move renewable energy from resource-rich northern regions to the industrial-heavy south. Companies like 50 Hertz are investing billions in transmission upgrades, most of which will be undergrounded as required by new national law to address public acceptability challenges. While progress has been made in streamlining and accelerating permitting, the move toward undergrounding emphasizes aesthetic concerns rather than the climate risk mitigation focus often seen in the U.S., where undergrounding is linked to reducing wildfire and extreme weather risks. BDEW estimates this requirement will significantly increase the overall cost of Germany's transmission buildout.

Considerations for the U.S.

In contrast, the U.S. emphasizes customer-centric innovations, such as virtual power plants (VPPs) and demand-side management. Demand-side management programs in the U.S. incentivize customers to reduce or shift their energy consumption during peak demand periods, helping to balance supply and demand without requiring large-scale infrastructure investment. While Germany's approach prioritizes grid stability and resilience through centralized solutions, the U.S. model has focused on greater consumer engagement, enabling more flexible, responsive, and decentralized grid management. This model allows for flexibility and resilience at the distribution level, as local assets can be dynamically utilized to respond to changing grid conditions, reduce costs, and optimize energy use on a more granular level.

Key Finding 3: Sector Coupling as a Big (and Risky) Lever

What is Sector Coupling

Sector coupling refers to integrating electricity, heat, transportation, and industrial sectors to maximize renewable energy use across sectors by leveraging the temporal and locational demand flexibility. Germany's reliance on sector coupling is driven by the need to balance its energy surplus, especially as it anticipates having 380 GW of installed capacity by 2030, against peak demand of only 60-80 GW in December. Coupling the power sector with the hydrogen sector enables the storage of renewable energy in molecular form, utilizing hydrogen as an energy carrier. Excess electricity generation within the transportation sector can be used to charge electric vehicles or produce hydrogen for use in heavy-duty transportation applications.

During the mission, the delegates met with Salzgitter AG, one of the world's largest steel manufacturers, to explore an exemplary case of industrial sector coupling. Salzgitter is undertaking a significant effort to decarbonize its steel production—a sector responsible for 30% of Germany's industrial greenhouse gas emissions. The company plans to produce 'green steel' by leveraging renewable electricity and replacing fossil fuels with hydrogen in high-temperature processes. This initiative highlights the role of sector coupling, as it depends heavily on both a reliable renewable energy supply and the development of robust hydrogen infrastructure.

Despite the promise of green steel, significant challenges remain, and Salzgitter is at the forefront of addressing them. Decarbonizing steel production will require a two-phase approach. First, the company must ensure that the electricity used comes exclusively from renewable sources. Second, hydrogen must replace fossil fuels in high-heat processes—a step that depends on generating hydrogen via electrolysis, which requires substantial renewable energy. These interconnected challenges underscore the complexity of scaling green steel production and highlight the importance of advancing renewable energy and hydrogen infrastructure in parallel. For the U.S. delegation, where progress in reducing industrial emissions has been limited, it was encouraging to see that steel production can be relatively straightforward to decarbonize, as lower-carbon fuels can replace fossil fuels with minimal changes to existing processes.

Challenges

While sector coupling presents significant opportunities for decarbonization, it also comes with risks. As BDEW and 50 Hertz discussed, implementing sector coupling requires the development of new infrastructure, such as hydrogen networks, transmission capacity, and large-scale storage solutions. This type of infrastructure is capital-intensive and may face delays due to regulatory and technical challenges. Additionally, the timeline for deploying hydrogen as a

viable energy source is long, with complete infrastructure buildout not expected until the 2030s. Despite these hurdles, sector coupling remains a crucial strategy for Germany to balance its energy system.

Considerations for the U.S.

The U.S. can learn from Germany's approach to sector coupling, particularly integrating transportation and industrial processes into energy system planning. However, given the high upfront costs and long timelines, the U.S. might benefit from adopting a more flexible and modular approach to integrating these sectors. This could involve starting with pilot projects and scaling incrementally, allowing for innovation and learning. For example, the U.S. could explore smaller-scale hydrogen hubs or demand-driven investments in renewable energy infrastructure, particularly in industrial regions, to begin building the necessary supply chains and market incentives for broader sector coupling. Adopting a phased, adaptable approach would help manage costs and risks while advancing toward a more integrated, low-carbon future.

Key Finding 4: Cost of Transition and Impacts on Public Acceptance

Public Sentiment

Environmental issues and renewable energy have been central topics in German education for generations. In recent years, many schools have introduced a Climate Week, inspired by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), during which students focus on a variety of environmental topics. Additionally, the government organizes a contest encouraging students to develop ideas, concepts, and activities related to environmental protection. Over the years, numerous government-led campaigns have aimed to educate the public about the impacts of climate change and the benefits of renewable energy. Germany's media landscape, including both traditional outlets and digital platforms, has played a key role in raising awareness. Through advertisements, documentaries, and reports, the media consistently highlights the importance of reducing carbon emissions and transitioning to renewable energy, helping to inform and motivate the broader public on the urgency of the climate crisis. As a result, 75% of the German population supports the Energiewende and its climate goals. However, concerns about the transition's high costs are growing, particularly as Germany moves toward electrifying heating systems and expanding renewable energy. There was some concern about a shift in public opinion if the financial burden becomes too great, especially if energy prices continue to increase.

Tipping Point Concerns

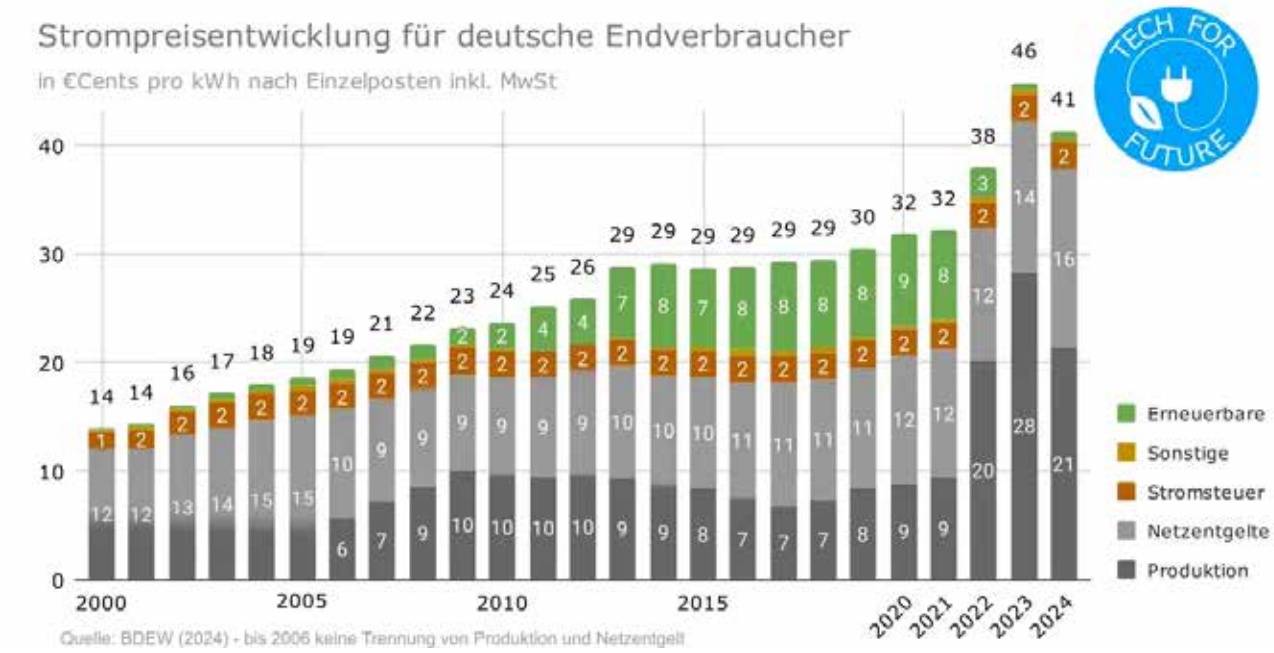
Germany's ambitious energy transition, mandated at the national level, has resulted in notably higher energy costs for consumers—averaging around 40 euro cents per kWh for residential customers (Figure 4).[1] Since 2010, nearly one-third of this price has been attributed to the *Netzentgelte*, a charge designed to fund grid infrastructure enhancements. In response to the 2022 energy crisis, the tax on renewable energies was first temporarily and then permanently removed in 2023. However, rising electricity costs risk undermining public support for the transition, particularly if its benefits are not equitably distributed across all sectors of society. SEPA's discussions with stakeholders emphasized that maintaining public trust is crucial to preventing backlash against the higher costs associated with Energiewende.

Considerations for the U.S.

The U.S. will need to maintain public trust and keep customer costs low during the energy transition. At the same time, focusing on public education and support—like in Germany—may help secure some acceptance of potential price increases. While Germany's centralized model has led to rapid progress, it may also reach a financial tipping point. The U.S., with its more decentralized approach, may be better positioned to balance costs and benefits across different regions and stakeholders; however, it has come at the expense of speed and scale.

1 It is worth noting that average electricity bills are lower for German customers as compared to the U.S., despite higher retail prices. This reflects the smaller size of German homes and less reliance on space conditioning.

Figure 4. The Cost of Electricity for Customers in Germany Since 2000 and Its Annual Composition



Source: Blümm, F (March 8, 2024). Strompreisentwicklung für deutsche Endverbraucher. Tech for Future.

Key Finding 5: Shared Challenges Around Transmission Expansion and Interconnection Queue Management and Cost Allocation

In Germany, the Energiewende has led to a rapid build-out of renewable generation resources through supportive mechanisms, including take-or-pay contracts. This structure has been crucial in driving wind and solar expansion, as it ensures that project developers are compensated even when their energy production is curtailed due to grid limitations or lack of demand. However, the accelerated growth of renewable generation under the Energiewende has exposed some structural challenges, particularly the high curtailment levels. Renewable energy sources, such as wind and solar, often generate power at times when it cannot be fully consumed, either because of insufficient transmission capacity or because generation does not align with peak consumption periods. As a result, significant amounts of renewable power go unused, even as take-or-pay contracts require compensation for this curtailed energy, adding a financial burden to the system and, ultimately, customers.

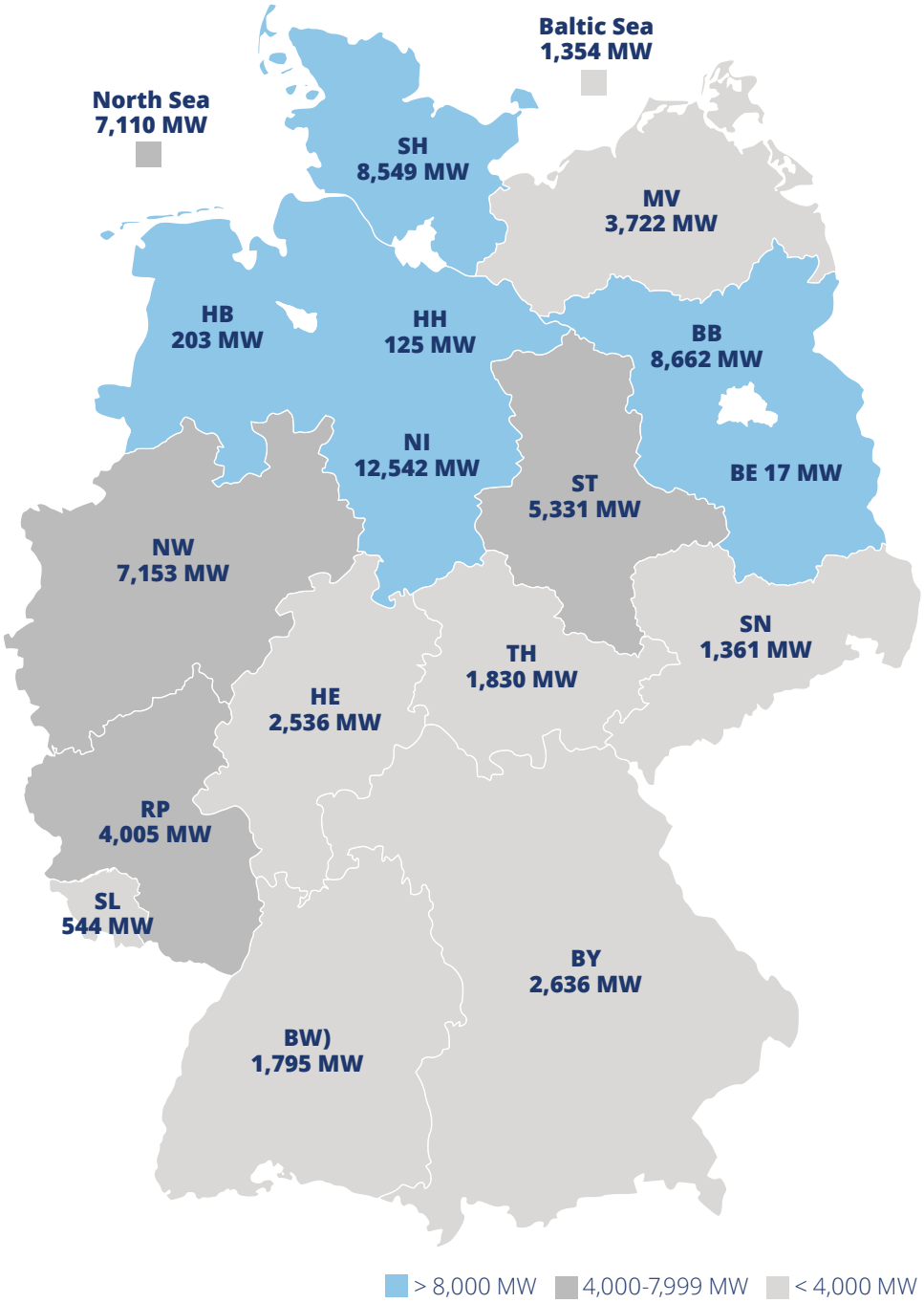
While beneficial for early-stage deployment by de-risking investments in renewable infrastructure, the take-or-pay approach also highlights a broader issue in the energy market. As more renewable projects come online, the costs of compensating for curtailed energy increase, impacting consumers and potentially stalling further development if these expenses become too onerous. To maintain the momentum of the Energiewende and balance the financial load, Germany may need to consider alternative market structures that better align energy generation with demand, support investment in grid flexibility and storage, and create market signals that incentivize both production and consumption at optimal times.

Transmission Expansion Challenges

Germany faces the challenge of an uneven distribution of renewable energy resources, particularly wind power, which is heavily concentrated in the North, while its industrial hubs and densely populated regions are located in the South (Figure 5).

To address this imbalance, Germany has been building transmission lines to connect northern generation to southern demand. As of September 2023, 2,700 kilometers of transmission lines have been completed, with an additional 1,444 kilometers under construction, including the three major lines shown in Figure 6. However, 9,845 kilometers remain in the permitting stage, highlighting

Figure 5. Wind Energy in Megawatts Per State and Offshore in Germany in 2023



69,475 MW Total Capacity
- 61,010 MW on land
- 8,465 MW at sea

30,243 Installations
- 28,677 on land
- 1,566 at sea

3,896 MW New Installations
- 3,567 MW on land
- 329 MW at sea

142.1 TWh Electricity Generated
- 118.2 TWh on land
- 23.9 TWh at sea

27%: Share of gross electricity consumption

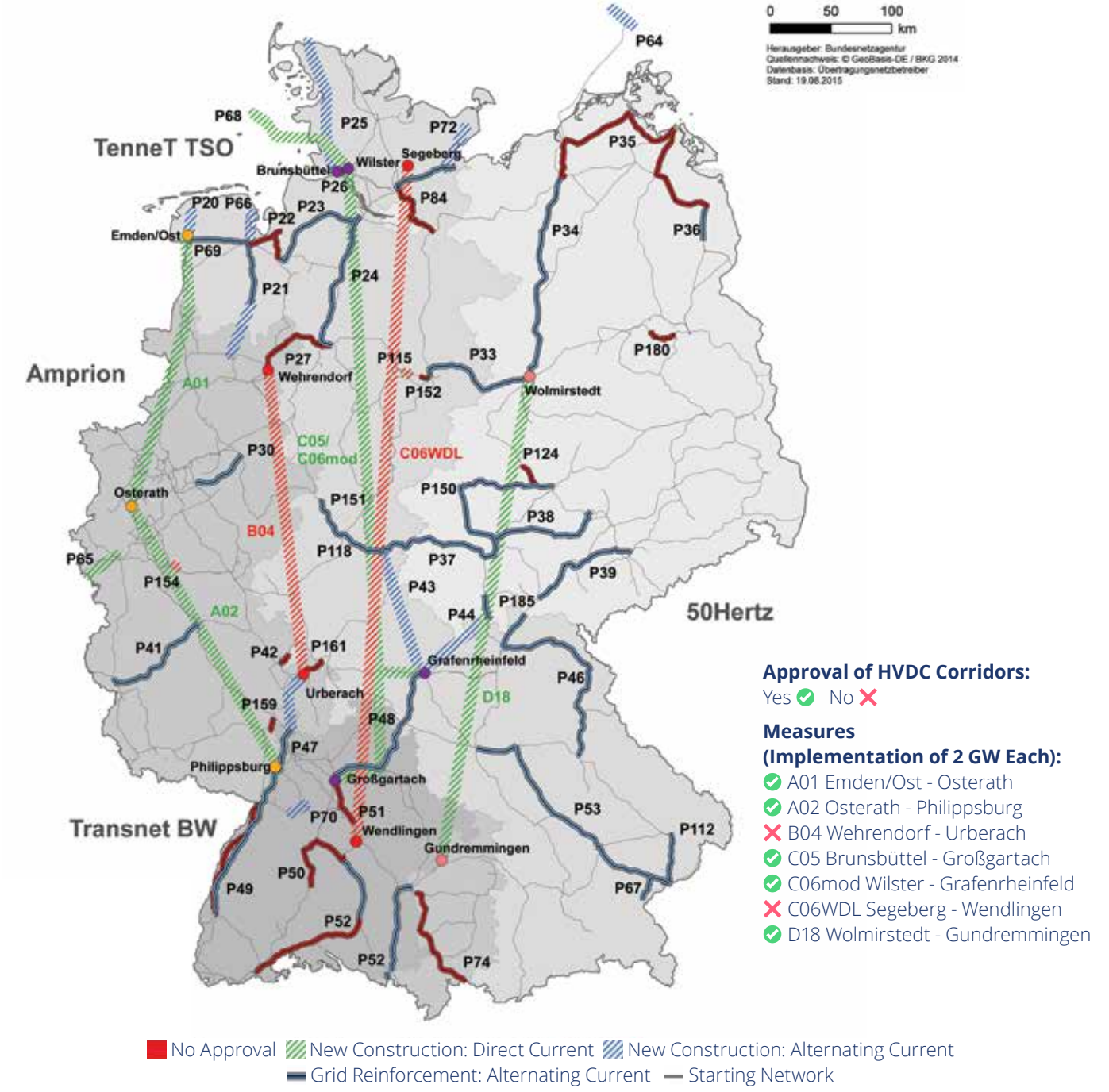
Average Wind Turbine:
- Output: 4,788 kW (up 10% from 2022)
- Rotor Diameter: 141 meters (up 3% from 2022)
- Total Height: 206 meters (unchanged)

Source: Bundesverband WindEnergie (n.d.). Zahlen und Fakten. Recreated by SEPA.

significant challenges related to public opposition and complex regulatory processes. To overcome these hurdles, Germany has moved to underground transmission lines, particularly for high-voltage direct current (HVDC) projects. Although underground lines are less visually disruptive and generally garner greater public acceptance, they are significantly more expensive to build and pose additional technical challenges.

Similarly, in the United States, the expansion of transmission infrastructure has encountered major obstacles, including lengthy permitting and environmental review delays, land-use conflicts, and local opposition.

Figure 6. Planned and Approved Transmission Lines in Germany for 2024



Source: Netzausbau. (2024). Netzentwicklungsplan 2037/2045: Poster overview.

While the U.S. has explored options like regional cooperation and federal interventions to streamline the process, challenges remain. Both countries face a pressing need for upgraded and expanded transmission networks to support the integration of renewable energy, and the experiences in Germany and the U.S. underscore the difficulty of balancing technical requirements, cost, and public acceptance in building out essential enabling infrastructure.

Interconnection Queue Management

In Germany, a policy waiving grid fees for new energy storage projects built before 2028 has triggered an unprecedented surge in interconnection requests,

particularly in the 50 Hertz territory. Following the rule change, annual requests skyrocketed from just 12 to 271. This policy has driven 80 GW of storage capacity into the interconnection queue, far exceeding the forecasted need of 5 to 10 GW, raising uncertainty about how many of these projects will ultimately be realized. Developers appear to be leveraging the waived fees to secure interconnection capacity, even if they do not intend to build all of these projects—a trend also observed in the U.S. interconnection queue. In the U.S., renewable energy projects with varying likelihoods of financial viability often clog the queue, as developers reserve multiple locations to maintain future project flexibility. Many of these projects never move forward. A similar outcome seems likely in Germany unless measures are introduced to better align interconnection requests with realistic development plans and actual grid requirements.

Conclusion

Germany's Energiewende provides some valuable lessons for the U.S. energy sector, particularly in terms of national policy implementation, grid expansion, and sector coupling. While Germany's top-down approach has accelerated renewable energy deployment and grid reliability, it also highlights challenges like high costs, technology lock-in, and maintaining public support. The U.S. can learn from Germany's emphasis on emerging technologies, sectoral coordination, and hydrogen infrastructure while adapting these strategies to fit its own market structure and regulatory environment. The focus on sector coupling—integrating industries, energy, and infrastructure—provides a promising framework for decarbonizing multiple sectors simultaneously, which could be valuable for U.S. planning. However, the U.S. will need to balance large-scale infrastructure development with customer-centric innovations, such as demand response and behind-the-meter solutions. Germany's experience also underscores the importance of addressing affordability and public acceptance, particularly as costs rise. While the specific paths may differ, the U.S. and Germany can benefit from continued dialogue, sharing best practices and lessons learned to support a clean, affordable, and reliable energy future. To be successful in the fight to mitigate climate change, no country can go on the journey alone. Instead, it will take working together with other countries globally to progress actional solutions toward a carbon-free future.



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