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The Sun Has Won

Research Note: German Renewables Growth and Economic Impacts

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Summary: Germany continues its progress toward a cleaner, greener, more efficient economy. Renewable sources provided 55% of total German electricity generation in 2023 and surpassed 60% of total generating capacity. The rise in renewable generation is contemporaneous with 1) an increase in stability of the German grid, 2) an increase in GDP, and 3) a reduction in CO_2 equivalent emissions. After spiking at the outset of war in Ukraine, wholesale electricity prices in Germany are falling and are now modest compared with peer economies in Europe. While the German economy is facing a variety of challenges, leading The Economist to wonder whether the country is "once again the sick man of Europe", that man is breathing ever cleaner air and has an increasingly capital-efficient energy production system. Ongoing deployment of renewable energy production will lead to greater fitness and improving economic health. This Research Note updates and expands reporting and analysis from The Sun Has Won.[1]

1. The German electricity grid and economy are becoming more stable, more green, and more capital-efficient

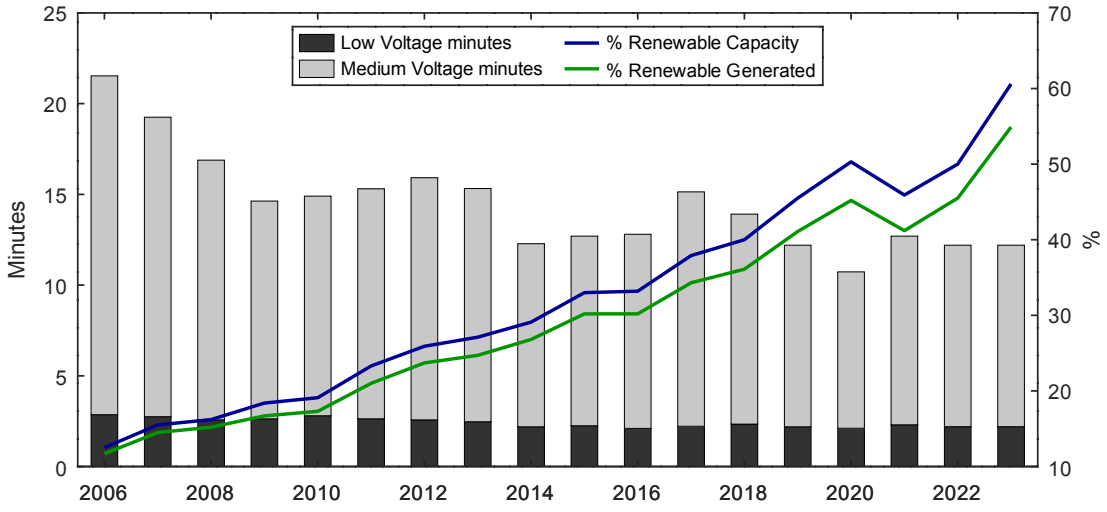

Figure 1: German national grid interruptions since 2006, share of renewable electricity capacity, and share of renewable electricity generated. (Sources: German Federal Network Agency and Fraunhofer ISE)

1.1 Renewables contribute to grid stability

Renewable energy skeptics frequently argue that an increasing reliance on variable wind and solar generation will *necessarily* result in grid instability. In reality, the German electricity grid became more stable between 2006 and

1 The Sun Has Won, Part 1: Market Inevitabilities In Electricity Production, Robert Carlson, July, 2022, Planetary Technologies. https://www.planetarytech.earth/s/The_Sun_Has_Won_Rob_Carlson_July2022.pdf

2023, while the share of renewable electricity generated across the grid grew from 6% to 55% (Figure 1).[2],[3] Over that same period, the absolute amount of electricity generated from nuclear and fossil-fueled power fell by 50% and 60%, respectively.[4] On a monthly basis, renewable generating capacity now typically exceeds 60% of total generating capacity, with some variation depending on the season and weather.[5] The anti-correlation of renewable generation and grid instability across an economy and a grid the size of Germany's stands as sufficient proof to refute the stability skeptics. Yet the case is stronger; the increase in grid stability has been causatively attributed to 1) the vast majority of photovoltaic (PV) solar installations in Germany being at the community scale or smaller, and 2) those distributed installations accounting for more than half the total PV-generating capacity in the country.[6],[7] At a minimum, one can conclude that renewable generation of at least 55%, and rising, is compatible with increasing grid stability, if system administrators choose to pursue these combined goals. Greater reliance on renewable sources will be further facilitated by large-scale deployment of battery storage. There is no reason to expect this result to be localized to Germany. Consequently, given the combined economic benefits of lower electricity prices and fewer interruptions, concerns about grid stability around the world may *accelerate,* rather than retard, PV adoption. The grid stability benefits of distributed generation may become recognized as a means to reduce spending on infrastructure maintenance and upgrades, an advantage that improves the value proposition of rooftop and community solar, particularly when combined with local battery storage.

1.2 The German grid is greener and more efficient

The Sun Has Won, Part 1 highlighted that PV is now the most capital-efficient means to produce energy. That is, a new dollar or euro spent on PV will produce more energy than any other source. Wind is not far behind PV in this regard, and, assuming the techno-economic trends identified in *Part 1* continue, we should expect that together these renewable sources will eventually come to dominate electricity production globally. As an early adopter of both wind and PV, Germany provides an example of how these technologies can impact an economy.

Germany is frequently presented as a poster child of what is going right, or going wrong, for an economy working through an energy transition, in this case the transition from fossil fuels to electrification and renewables. An understanding of the impact of renewables is complicated by other trends, such as Germany's abrupt turn away from nuclear energy, the broader economic transition from manufacturing to services, labor availability and immigration, and international competition.[8],[9]

To be sure, German economic growth has recently lagged both the U.S. and Europe overall, with *The Economist* wondering in a headline whether Germany is “once again the sick man of Europe”.[10] Nevertheless, the air this man is breathing is cleaner, and his electrical circulatory system is more efficient and greener.

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2 “Power interruptions in 2019”, German Federal Network Agency, 22 October, 2019. https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2020/20201022_SAIDIStrom.html?nn=265778

3 “Key figures for electricity supply interruptions”, German Federal Network Agency. https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Versorgungssicherheit/Versorgungsunterbrechungen/Auswertung_Strom/start.html

4 “In Defense of the Energiewende”, Nick Tsafos, 24 August, 2020. https://www.csis.org/analysis/defense-energiewende; and https://twitter.com/ntsafos/status/1478010911143219201

5 Energy-Charts: https://energy-charts.info/charts/renewable_share/chart.htm?l=en&c=DE&year=2023

6 p. 30, “Recent Facts about Photovoltaics in Germany”, Harry Wirth, Fraunhofer ISE, 15 May, 2021. https://www.ise.fraunhofer.de/en/publications/studies/recent-facts-about-pv-in-germany.html

7 p.18, “Photovoltaics Report”, Fraunhofer Institute for Solar Energy Systems, ISE, 27 July, 2021. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

8 “As German industry declines, the Ruhr gives hope”, *The Economist*, 15 February, 2024. https://www.economist.com/europe/2024/02/15/as-german-industry-declines-the-ruhr-gives-hope

9 “Germany’s Days as an Industrial Superpower Are Coming to an End”, Wilfried Eckl-Dorna, et al, *Bloomberg*, 9 February, 2024. https://www.bloomberg.com/news/features/2024-02-10/why-germany-s-days-as-an-industrial-superpower-are-coming-to-an-end

10 “Is Germany once again the sick man of Europe?”, *The Economist*, 17 August, 2023. https://www.economist.com/leaders/2023/08/17/is-germany-once-again-the-sick-man-of-europe

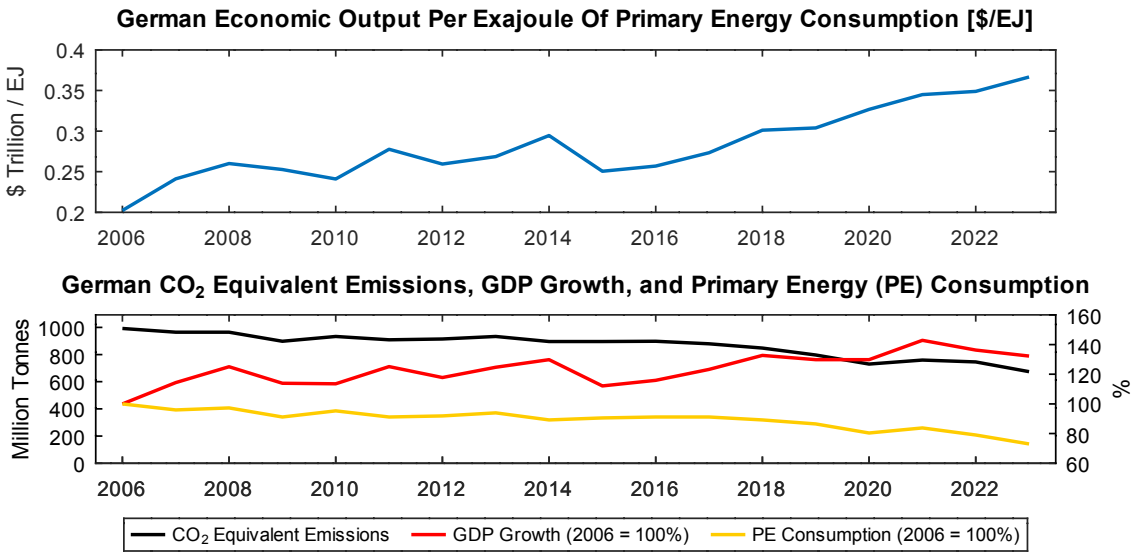

Figure 2: Top: German economic output per exajoule of primary energy consumption (calculated as GDP per unit of primary energy consumption). Bottom: German CO2 equivalent emissions, GDP growth, and Primary Energy (PE) Consumption. (Sources: World Bank, Destatis, Clean Energy Wire, Fraunhofer Institute)

The energy efficiency of the German economy, measured here as GDP per unit of primary energy consumed, has improved considerably over the period 2006–2023 (Figure 2, Top Panel). By this measure, German economic productivity rose more than 80% over the last 17 years. Figure 2 also documents (Bottom Panel) that German CO_2 equivalent emissions have fallen over this time period, while GDP has risen about 30%. Notably, economic productivity grew more than twice as much as GDP on a relative basis, due in part to an overall 27% decline in primary energy consumption since 2006.[11]

While the total decline in Germany's 2023 emissions must carry the caveat that industrial activity also declined, the drop in emissions from energy production was more than twice as large as that from industrial activity.[12] A recovery in manufacturing activity that is reliant upon fossil fuels might cause a future apparent, temporary slowdown in emissions reductions.[13] Yet the broader trend is clear: over the period 2006–2023, total emissions fell by 32% and energy industry emissions fell by approximately 50%.[14] The German electricity grid is substantially cleaner and more capital-efficient than it was fifteen years ago.

The standard presentation of the relationship between GDP and energy use is “energy intensity”, the energy consumed per unit GDP. The inverse of this quantity is also useful for evaluating the economies in transition. One thread running through *The Sun Has Won* series of reports is an examination of the financial incentives driving the energy transition. Investors, particularly large institutions, may be most interested in the simple question of how much money they will make by choosing one investment over another. Based on the improvement in economic output per unit energy consumed, investors are increasingly benefiting from the shift to renewables on the German grid.

11 AG Energiebilanzen, via Bundesministerium für Wirtschaft und Klimaschutz. https://www.bmwk.de/Redaktion/DE/Dossier/strommarkt-der-zukunft.html; see also “Economic growth, power & energy consumption, GHG emissions1990 – 2022”, Clean Energy Wire. https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts
12 “German emissions fall by a fifth amid stagnant industrial output”, Patricia Nilsson and Sam Jones, *Financial Times*, 4 January, 2024.
13 “Germany’s emissions hit 70-year low as it reduces reliance on coal”, Mimi Ibrahim, *The Guardian*, 4 January, 2024. https://www.theguardian.com/business/2024/jan/04/germany-emissions-hit-70-year-low-reduces-reliance-coal
14 Drop in coal power and weak economy push German emissions to lowest level in 70 years – report, https://www.cleanenergywire.org/news/drop-coal-power-and-weak-economy-push-german-emissions-lowest-level-70-years-report

2. The German economy in the broader European context

2.1 Building a resilient and efficient economy

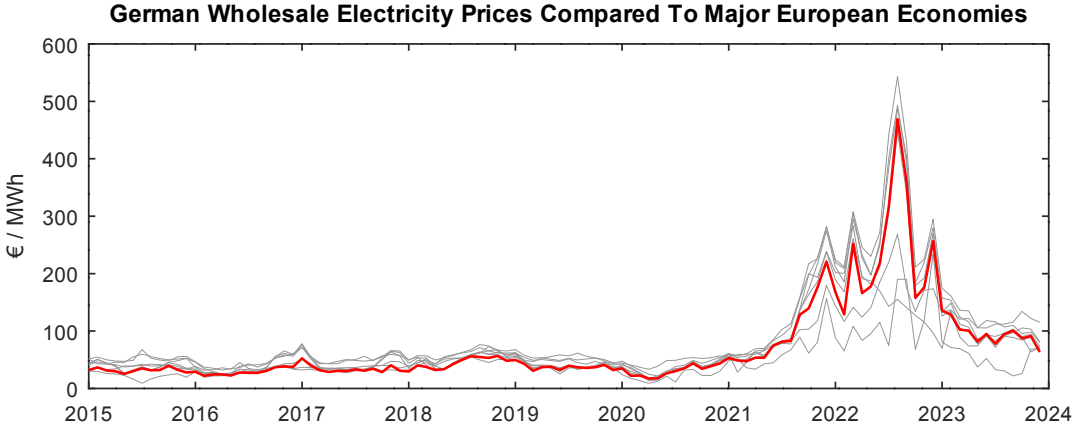

Figure 3: German wholesale electricity prices compared to prices in Switzerland, Spain, France, Italy, The Netherlands, Poland, and Sweden. (Source: EMBER)

One measure of progress in implementing the energy transition is the price of electricity. Sustained high prices might indicate a mismatch between demand and supply, or that new renewable supplies are more costly than the sources they displace. German wholesale electricity prices skyrocketed following the Russian invasion of Ukraine, but have now fallen most of the way to their pre-war level, and appear to be on a trajectory to continue falling (Figure 3).[15] To be sure, some of this recovery is due to successful replacement of gas supplies from Russia with supplies from elsewhere. But that replacement was also facilitated by the continued increase in renewable generation (Figure 1), all the while improving the stability of the grid and reducing total emissions (Figure 2). Compared to peer European economies, German wholesale electricity prices are trending to the lower end of the distribution.

Electricity prices should fall further as nations across Europe continue to deploy lower cost PV and wind and increasingly deploy batteries. Different countries will proceed at different rates. With the transition to distributed energy production, energy prices will be set more by local policies than by international markets, as has been the case for fossil-fueled energy production for two centuries. While the German economy might be ailing today, going forward its health will improve and will be less subject to the whims of international energy markets and more in the control of domestic policymakers. Those policymakers should be mindful that building and maintaining a new energy production system based on renewable sources will require different investments than did the fossil-fueled system.

2.2 Investing for the future

Large variations in annual PV installation rates are an indication that more, and perhaps urgent, attention is required to improve policies influencing deployment. European PV installations grew to a rate of 40% YoY in 2023, which is a large fluctuation up from the prior trend, and which is forecast to fall back into a range of 11–19% annually over the next four years. This fluctuation is notable because it is attributed to a 2022 slowdown in installations due to local labor shortages.[16],[17] While installation across much of the continent appears to have caught up with the prior backlog,

15 "European power price tracker", EMBER. https://ember-climate.org/data/data-tools/europe-power-prices/
16 "Solar Panels Piling Up in Warehouses in Energy-Starved Europe", *Bloomberg News*, 27 September, 2022. https://www.bloomberg.com/news/articles/2022-09-27/solar-panels-piling-up-in-warehouses-in-energy-starved-europe
17 SolarPower Europe (2023): EU Market Outlook for Solar Power 2023-2027. December 2023. https://www.solarpowereurope.org/insights/outlooks/eu-market-outlook-for-solar-power-2023-2027/detail

in some local markets labor shortages remain the primary cause of project delays of up to one year. In this difficult environment, Germany managed to maintain a PV installation rate of approximately 1.2 GW per month in 2023.[18] This pace may be difficult to sustain.

Due to the aftereffects of World War II, Germany's population, relative to other developed countries, is composed of a surfeit of workers imminently reaching retirement age, and a deficit of those entering the job market.[19] The expected decline in working age population is so concerning that in a decade it may be "too small to keep the economy functioning as it does today".[20] Over time, this deficit could result in a shortage of skilled labor and thereby jeopardize Germany's ability to increase, or perhaps even maintain, the current pace of renewables deployment. International peer countries, notably China, are deploying renewables because they are the cheapest sources of energy, and therefore provide a sustainable—in both senses of the word—competitive economic advantage.[21] Moreover, China continues to shift the energy sources for new renewables manufacturing plants to wind and solar; this feedback loop ensures that new manufacturing infrastructure is powered by the lowest-cost, carbon-free, most capital-efficient resource available. To realize this same opportunity, German policymakers must acknowledge and address the explicit connection between maintaining an adequate skilled labor pool and transitioning to fully renewable energy sources that enable building a competitive 21st century economy.

2.3 To carbon neutral, and beyond

Deploying lower-cost, capital-efficient renewable electricity generation is just the beginning of the energy transition. Fossil fuels remain integral to many industrial processes. At approximately 20% total penetration, Germany currently trails the EU average total share of energy from renewable sources (that is, not just electricity), although it is at about the same share as Spain, France, and Italy.[22],[23] Eliminating fossil fuels entirely is an opportunity to improve both energy efficiency and capital efficiency. Over time, Germany will replace fossil-fueled industrial processes with electric heating and with electrically-produced hydrogen, and thereby further reduce emissions.[24],[25] Beyond greening the grid, the German government recently announced ambitious plans to achieve net-negative carbon emissions across the economy by 2060 by developing and deploying a wide range of carbon-sequestration methods.[26] Implementing this broader, economy-wide transition from burning fossil fuels to pulling carbon out of the atmosphere, while running everything on electricity, will require additional careful investment in sufficient skilled labor and in new technology. Here, though, Germany could find a cure for what ails it.

For more than a century the German economy thrived when focused on precision engineering and high quality manufacturing. Throughout this period, that manufacturing base was powered primarily through inefficient combustion of fossil fuels. Now Germany is facing dual challenges of international competition and meeting the social and economic goals of eliminating the use of fossil fuels. Retraining design and manufacturing muscles to enable the domestic use—and international export of—renewable generation and carbon capture technologies provides an opportunity to return the German economy to a state of rude health.

18 Bundesnetzagentur Offers Upward Revision Of 2023 Solar Additions With 14.6 GW Combined Capacity, Taiyang News, 22 February, 2024. https://taiyangnews.info/germany-kickstarts-2024-with-gw-scale-pv-installations/
19 "The German economy: from European leader to laggard", *The Economist*, 17 August, 2023. https://www.economist.com/finance-and-economics/2023/08/17/the-german-economy-from-european-leader-to-laggard
20 "Germany's Days as an Industrial Superpower Are Coming to an End", Wilfried Eckl-Dorna, et al, *Bloomberg*, 9 February, 2024. https://www.bloomberg.com/news/features/2024-02-10/why-germany-s-days-as-an-industrial-superpower-are-coming-to-an-end
21 *The Sun Has Won*, Carlson, 2022.
22 "Sweden, Finland, Latvia: Which EU countries use the most renewable energy?", 7 February, 2023. EuroNews.Green https://www.euronews.com/green/2023/01/20/which-european-countries-use-the-most-renewable-energy
23 EuroStat https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics
24 "First electric cars. Next, electric factories?", The Economist, 15 February, 2024. https://www.economist.com/briefing/2024/02/15/first-electric-cars-next-electric-factories
25 "Germany Starts Auction For Green Industry Worth Up to €4 Billion", Petra Sorge, Bloomberg, 11 March, 2024. https://www.bloomberg.com/news/articles/2024-03-11/germany-starts-auction-for-green-industry-worth-up-to-4-billion
26 "Germany to adopt 2060 target for net-negative greenhouse gas emissions", *Clean Energy Wire*, 28 February, 2024. https://www.cleanenergywire.org/news/germany-adopt-2060-target-net-negative-greenhouse-gas-emissions

Acknowledgements

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Rob Carlson, PhD, is a Managing Director of Planetary Technologies, an early stage investment firm. Carlson is an entrepreneur, author, and scientist. He is the namesake of “Carlson Curves”, which describe the pace of improvement of biological technologies (Life 2.0, *The Economist*, 31 Aug, 2006), and the originator of the first estimates of global biotech revenues. Carlson is the author of the book *Biology is Technology: The Promise, Peril, and New Business of Engineering Life*, published in 2010 by Harvard University Press; it received the PROSE award for the Best Engineering and Technology Book of 2010 and was named to the Best Books of 2010 lists by writers at both *The Economist* and *Foreign Policy*. Carlson is an Affiliate Professor in the Allen School of Computer Science & Engineering at the University of Washington and earned a doctorate in Physics from Princeton University in 1997. Additional writing and a weblog can be found at www.synthesis.cc.

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Planetary Technologies, LLC, identifies and builds scalable technologies that will enable the world to mature beyond fossil fuels at the pace necessary to avoid unsustainable warming. The Planetary Technologies team has a combined five decades of experience in startup operations, engineering, product development, science, strategy, techno-economic analysis and forecasting, and venture capital. Our strategic analysis and quantitative research is cited prominently by governmental policies and roadmaps in the United States, Great Britain, the European Union, the OECD, and the UN; we directly advise the U.S. government on matters of economics, security, and regulatory policy.

