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How to retire coal, smarter and faster

Even as coal power continues its steady decline in the United States, more than a hundred plants still have no retirement plans — a gap large enough to derail national climate goals. A new study led by UC Santa Barbara researchers offers a way forward, showing how targeted, data-driven approaches could help accelerate the transition.

Published in [Nature Energy](#), the study tackles a critical question: if market forces have already driven many coal plants to close, why are so many still running? Despite years of decline, roughly 105 gigawatts of coal capacity — representing 114 plants — are still slated to operate through 2035, even though a complete phaseout by that date is widely considered essential for meeting U.S. net-zero emissions goals.

“Coal is complex — there’s no single right way to deal with it,” said Sidney Gathrid ’22, the study’s lead author. “Our goal was to build tools that reflect that complexity, so different actors can take on different facets of the problem. There’s no one straightforward path, and we wanted to do research that represented that reality.”

Working with [Grace C. Wu](#), an assistant professor in the Environmental Studies Program and senior author on the paper, Gathrid and his team show that reaching those goals will require policymakers to move beyond age-based or one-size-fits-all approaches — and instead focus on the specific contexts that accelerate the

retirement of certain coal plants.

To do that, the researchers — including Jeremy Wayland, Stuart Wayland '22, and Ranjit Deshmukh, an associate professor in the Environmental Studies Program and the Bren School of Environmental Science & Management — developed a new framework combining graph theory and topological data analysis to classify the entire U.S. coal fleet into eight distinct groups based on 68 technical, economic, environmental and socio-political factors. They also introduced a “contextual retirement vulnerability” score that measures how susceptible each plant is to early retirement by comparing it to facilities that have already announced closures.

The framework goes a step further by identifying “retirement archetypes” — patterns that explain why plants in each group are retiring. These range from regulatory and health-based drivers to unfavorable economics or political pressure, offering a clear set of levers that can be applied to similar facilities elsewhere.

“Instead of asking only why coal plants retire, we asked how we can make retirements happen faster — and in ways that are efficient and grounded in data,” Gathrid said. “Our framework helps policymakers and advocates identify where they can have the biggest impact.”

The study began as Gathrid’s senior thesis in UCSB’s Environmental Studies Program, supported by the campus’s Manalis Leadership Fellowship, sponsored by Howard and Lisa Wenger, and evolved into a years-long collaboration. Wu said the project’s scope and impact are rare for undergraduate research.

“This is Ph.D.-level work,” Wu said. “It’s extremely unusual for a project that started as a senior thesis to reach this level of sophistication and impact. What’s exciting is that this framework doesn’t just describe which plants might retire — it shows how to accelerate those retirements using drivers that worked with other retired or soon-to-be retired coal plants.”

Using their model, the team grouped 198 active U.S. coal plants into clusters such as High Health Impacts Plants, Expensive Plants, and Plants in Anti-Coal Regions, each linked to specific vulnerabilities that can be targeted with policy or advocacy. For example, plants associated with high asthma rates and poor air quality could be prioritized through public-health campaigns and environmental enforcement, while those struggling financially might respond more effectively to economic incentives

or market-based mechanisms.

One striking example is Belews Creek in North Carolina — a nearly 50-year-old, 2.49-gigawatt coal plant that the study categorizes as both highly vulnerable to retirement and part of Group 0: Fuel Blend Plants. The facility can burn up to 50% natural gas, yet remains one of the nation's top particulate polluters, ranking 26th out of 198 for fine particle emissions. Financially, it's among the most unprofitable plants in the country, carrying roughly \$46 million in debt as of 2020.

Belews Creek is also located in a state seeing rapid growth in solar development and the implementation of coal debt securitization policies designed to help utilities transition away from uneconomic fossil assets. "Given the drivers for retirements in this group," the authors noted, "advocates can leverage state and utility clean energy targets." There were even preliminary discussions about replacing Belews Creek with a small modular nuclear reactor, but the plant's owner, Duke Energy, has since postponed its retirement — underscoring the financial and operational complexities that the UCSB framework aims to untangle.

"We can simplify nearly 200 plants into clear groups and pair each with evidence-based strategies," Wu said. "That's a powerful approach to a geographically diverse and politically fragmented challenge."

Their analysis found that about 28% of coal plants without retirement plans are already highly vulnerable to closure — potential "quick wins" for policymakers and advocates. But it also revealed that the least vulnerable plants are spread across several groups, underscoring the need for a diverse set of strategies to address the most persistent facilities.

The implications extend beyond coal. Because the model captures the multi-dimensional forces that shape real-world decisions — economics, politics, health and grid reliability — it could be adapted to other complex decarbonization challenges.

Wu, whose research focuses on sustainable energy transition planning, said the framework bridges mathematical and applied environmental science in a way that could transform how analysts and decision-makers approach energy policy.

"This work takes state-of-the-art mathematical tools and puts them into the practitioner's toolbox," she said. "It's flexible, transparent and reproducible — exactly what we need to make smarter, more strategic decisions about the energy

transition.”

Gathrid, now a co-founder of an AI and data start-up, Krv Analytics, based in Los Angeles, said the framework’s open-source design makes it especially valuable.

“The methods we developed are meant to be used,” he said. “Whether you’re working on coal, renewables or industrial emissions, the idea is the same — use the data you have to see where progress can happen first, and why.”

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