New model to help reframe the transition to low-carbon electric power

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Governments and societies around the world face increasing urgency in responding to climate change by accelerating the transition to a low-carbon energy system but differing views remain on the combination of energy technologies that will best achieve this goal. Identifying technological pathways is complicated by wide uncertainties in economic and technological factors.

Mort Webster and a team of Penn State researchers developed a model to help reframe the energy transition discussions. Their model demonstrates the value of flexible investment strategies and that many pathways are needed to meet the emissions reduction goals outlined in the Paris Agreement.

Webster hopes their findings, published in *Environmental Science & Technology*, will reverse policy recommendations emerging from research literature calling to adopt narrow assumptions that favor, or limit, certain technologies while advancing highly specific portfolio recommendations. The reason is simple: the future is hard to predict.

"There's a lot of great analyses and simulations out there, but many say 'this is the path' and draw a perfectly predictable line heading straight to the year 2050," said Webster, professor of energy engineering in Penn State's College of Earth and Mineral Sciences. "However, two years ago natural gas was $3 a gallon, and this summer it went up to $9 in California. Nobody saw that coming. How can we predict costs or how much fuel we'll be using in 2049?"

Webster noted that planning models with targeted mandates and specific recommendations are well-intentioned, but the reluctance to grapple with uncertainty limits their practicality. Conversely, Webster sees value in preserving options and even postponing some decisions, which follows a long-established decision science concept known as option value.

Webster sees advantages in dividing planning models into two separate investment strategies, near-term and long-term, as a more promising way to navigate the challenge of retiring existing electricity-generating capacity for new technologies. The flexibility gained from simply recognizing that we are more certain of near-term conditions, than those decades away, helps avoid the selective approach found in most academic and industrial literature.

The team's proposal is not without challenges. Many near-term and long-term strategies offer conflicting recommendations due to the vast amounts of capital investment, time and infrastructure some technologies require. For Webster though, that simply highlights the importance of broadening the technology portfolio with a focus on adaptability.

"We don't need to do everything today, that we need to do 30 years from now. Let's do some things now and give ourselves the ability to change our mind depending on how things evolve before we make the rest of the investments," said Webster.

Webster's team tested their proposal by simulating their model with 2,000 different scenarios of future conditions to identify the best technology pathways that minimized the average total costs across all futures. Operations and maintenance, new construction, variable fuel and non-fuel costs of generation were calculated as costs. To ensure feasibility, penalties for unmet electricity demand were also included.

The case study compared investment options in energy technologies such as nuclear, natural gas, solar, wind, geothermal, and coal, with and without carbon capture. The analysis showed a small number of portfolio types that included wind, solar, and natural gas with carbon capture worked well for a substantial number of possible futures, while other combinations were uncompetitive in any future.

The specific result did not surprise the team. The analysis, which accounts for uncertainty, option value, and technology groups that perform well when combined, demonstrated the limited usefulness of statements that a particular technology can or cannot contribute to a low-carbon future or that a commitment should be made to one specific long-term portfolio. The models also signaled near-term policies should focus on investments over the next decade that make progress toward decarbonization commitments without foreclosing options for additional future investments.

Webster, who is a faculty member in the John and Willie Leone Family Department of Energy and Mineral Engineering, said the results follow the collective approach of the department and college.

"In our department, we take a systems-wide approach and are always looking across multiple disciplines and resources," said Webster. "We are scientists and engineers who work on petroleum, on coal, on solar, or energy storage, but rather than promoting a particular energy source or technology, we see we can all collectively be a part of the solution to this complex challenge."

Webster believes reframing the conversation will help decision-makers sidestep scenario-specific plans that often lead to incoherent near-term plans or timid actions.

"If we want to reach a cumulative emissions reduction of 80% by 2050, we must embrace uncertainty and make strategic steps now that are flexible so that we can pivot to whichever way the future takes us," said Webster.

More information: Mort Webster et al, Transition to Low-Carbon Electric Power: Portfolios, Flexibility, and Option Value, *Environmental Science & Technology* (2022). DOI: 10.1021/acs.est.1c08797

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