Addressing energy technologies and policies that shape future sustainability

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A quickly growing global population presents a variety of challenges, and raises the critical question: How can we sustainably meet energy needs while considering—and preventing—environmental and human impacts? An ever-increasing demand for energy requires the development and maintenance of an underlying infrastructure providing important services and utilities, such as power and communications. As new energy technologies emerge, researchers need to consider factors such as materials and costs—but beyond the actual technologies, researchers also need to determine which policies and incentives will help ensure that the technologies are used efficiently. Research from MIT's Institute for Data, Systems, and Society uses data and models to better design and predict the outcomes of technologies and policies in the critical area of energy and environmental sustainability.

Smart grids and pricing

The increasing demand for energy—along with growing environmental concerns—have led to the engineering of modern power grids with the capacity to integrate renewable energy resources on a large scale. Although demand response and dynamic pricing are often considered a means of mitigating the uncertainties of renewable energy generation—and improving the system's economic and environmental efficiency—the real-time coupling of supply and demand creates significant challenges for guaranteeing reliability and robustness in the power system.

Research by MIT professors Munther Dahleh, Sanjoy Mitter, and research scientist Mardavij Roozbehani addresses these challenges by providing a framework for modeling and analysis of the dynamics of supply, demand, and clearing prices in a power system with real-time retail pricing and information asymmetry. The team found that new technologies intended to increase reliance on renewable energy could actually result in bringing down the power grid if they are not matched with careful pricing policies. This result indicates the need for a deeper understanding of consumer behavior in response to real-time prices, and a thorough modeling and analysis of the dynamics of the system, based on actual usage data.

Research from MIT Professor John Tsitsiklis and Yunjian Xu of the Singapore University of Technology and Design explores pricing mechanisms that might mitigate the effect of demand fluctuations on the significant ancillary costs in an electric power system. In the future, a certain percentage of electricity production is required by law in many states to come from renewable sources. A demand surge or a decrease in renewable generation may result in higher energy costs due to the deployment of "peaking plants"—which only run when there is high demand, and are associated with a much higher cost per kilowatt hour. Through a dynamic game-theoretic formulation, they showed that a new pricing mechanism could create an effective incentive for consumers to shift their power consumption—potentially reducing the need for long-term investment in peaking plants.

Evaluating energy technologies

The rate of improvement of the cost or other aspect of the performance of a technology depends on a variety of factors often rooted in technology design, materials, institutional design, human behavior, and policy decisions. Some types of technologies evolve more quickly than others. Understanding which types of technologies improve the most rapidly—and have the best potential to be effective—is critical when determining which low-carbon energy technologies merit consideration and investment.

Research from Atlantic Richfield Career Development Assistant Professor Jessika Trancik and her team compares different formulas—Moore's Law, Wright's Law, and others—for predicting how rapidly technology will advance, and develops a forecasting model using data spanning across many different industries. Their findings indicate that these simple models have some predictive power—with Wright's curve performing the best followed by Moore's curve—which, in turn, can inform decisions about which technologies and policies to pursue toward climate change mitigation efforts and other sustainability goals. In other work, Trancik has shown how the design of a technology affects its rate of improvement and thereby why some technologies may improve faster than others. This research further enables private and public investors to sensibly invest time and money in developing low-carbon energy.

"The basic challenge we face in addressing climate change is to achieve a complete decarbonization of energy systems. I am interested in whether this is possible, and how we can make it more likely," says Trancik. "Specifically, I ask: How should engineers, private investors, and policy makers invest inherently limited time and money to make this happen? Can we use data and models to help direct key areas of technology innovation to accelerate this transition?"

Trancik's research has uncovered reasons why photovoltaic (PV) technologies—an area of great interest to governments, researchers, and industry—have improved so quickly over time. Trancik has also looked at the implications of continuing to grow PV technologies. Their findings indicated that in order for some thin-films PV technologies to continue to develop at recommended rates, the production of the metals used as input materials would need to grow at an unprecedented rate— raising the question as to whether the necessary materials could even be available in the quantity needed. (This concern does not, however, apply to the most common PV technology based on silicon.) By looking at the projected PV metal requirements in a larger, historical context—using data on the changes in metals production over time—this research assesses how quickly metals production would need to be scaled up to meet the rapidly increasing PV deployment levels required by aggressive low-carbon energy scenarios.

Trancik's group has also looked at the evolution of both solar and wind energy in recent decades—and the potential for future expansion of these technologies in the future through climate change mitigation policies and national agreements. The report notes that solar and wind energy costs have dropped rapidly over the past few decades, as markets for these technologies have grown at rates far exceeding the original predictions. In the case of solar energy, for example, the cost of reducing emissions by replacing coal-fired electricity with photovoltaics has fallen at least 50-fold since 1976.

Modeling to understand outcomes of energy and climate policies

Policies directed at cutting carbon emissions from sources like power plants and vehicles can reduce rates of some of the health problems that are associated with air pollution. Research from Esther and Harold E. Edgerton Career Development Associate Professor Noelle Selin and her team looked not only at the potential health benefits of some carbon-reduction reduction policies, but also at the economic implications of these health benefits. The researchers looked at three climate policies achieving the same level of carbon reductions in the U.S.: a clean-energy standard, a transportation policy, and a cap-and-trade program. They compared the health benefits of each with the economic costs.

The team found that the health-related benefits could offset 26 percent of the cost to implement a transportation policy—and could equal more than ten times the cost of implementing a cap-and-trade program. This difference primarily reflects the large differences in the costs of the programs. Overall, policies aimed at specific sources of air pollution, such as power plants and vehicles, did not lead to substantially larger benefits than cheaper policies, such as a cap-and-trade approach.

Selin, along with MIT Sloan School of Management Assistant Professor Valerie Karplus and their research teams have developed a model that connects a model of China's provincial energy economy with an air chemistry model to look at how changes in energy policy translate into changes in projected emissions and air quality impacts, and examine impacts on human health and the economy.

"As countries work to implement their commitments under the recent Paris agreement to address climate change, our methods can help them find solutions that can have clear near-term benefits," says Selin. "Air pollution represents a substantial challenge throughout the world, and our goal is to inform strategies that can be used to improve human health. This work shows how modeling and analysis techniques can inform real-world policy problems."

More information: John N. Tsitsiklis et al. Pricing of fluctuations in electricity markets, *European Journal of Operational Research* (2015). DOI: 10.1016/j.ejor.2015.04.020

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