Study addresses the connection between technology development and emissions-reduction policies

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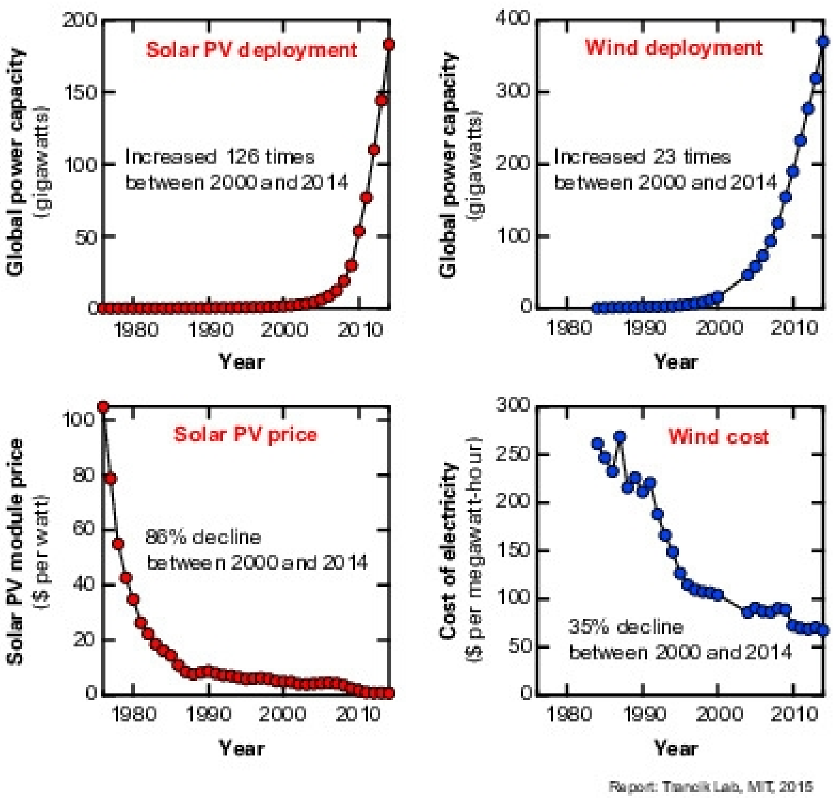

Figure 1: This chart shows worldwide deployment and costs of solar and wind energy. Since 2000, the rapidly growing deployment of solar photovoltaic (PV) and wind technologies (top figures) has been accompanied by dramatic declines in their costs (bottom figures). During that period, government policies rewarding the use of emissions-reducing technologies drove market growth, which in turn led to cost reductions due to private company innovation and

economies of scale. Credit: Massachusetts Institute of Technology

In December 2015, much of the world celebrated when 195 nations plus the European Union reached an agreement to address climate change and pledged to meet nationally determined emissions-reduction targets at the United Nations climate talks in Paris. But many experts have observed that the national targets in the Paris Agreement aren't sufficiently aggressive to meet the goal of limiting global warming to less than 2 degrees Celsius. Moreover, they worry that some countries won't be willing—or able—to meet their targets.

Now, an MIT analysis shows that if countries meet their emissions-reduction pledges to the Paris climate agreement, the cost of electricity from solar photovoltaic systems could drop by 50 percent and from wind systems by 25 percent between now and 2030. The reason: To cut their emissions, countries will need to deploy low-carbon technologies, and with that deployment will come technological innovation and lower costs, enabling further deployment.

The researchers estimate that if countries reinvest their savings as costs decline, they can increase their solar deployment by 40 percent and wind deployment by 20 percent—for the same level of investment. The lower costs of these and other low-carbon technologies will also help developing countries meet their emissions-reduction commitments for the future. Results of the MIT analysis were presented at the White House and referenced by negotiators in Paris.

In the study, Jessika Trancik, the Atlantic Richfield Career Development Assistant Professor of Energy Studies at the MIT Institute for Data, Systems, and Society (IDSS), and her colleagues showed that the impact of this mutually reinforcing cycle of emissions reduction and technology development can be significant. "The return on emissions reductions can be astonishingly large … and should feature prominently in efforts to broker an ambitious, long-term agreement among nations," she notes.

Trancik agrees that the targets as written are too weak to do the job. But she cautions that looking only at those targets doesn't tell the whole story. "There's something else going on below the surface that's important to recognize," she says. "If those pledges are realized, they'll require an expansion of clean energy, which will mean further investment in developing key clean-energy technologies. If good investment and policy decisions are made, the technologies will improve, and costs will come down." Thus, the act of cutting carbon emissions will drive down the cost of meeting current emissions-reduction targets and of adopting stronger targets for the future.

The study involved an interdisciplinary team of graduate students—Patrick Brown of the Department of Physics, Joel Jean of the Department of Electrical Engineering and Computer Ccience, and Goksin Kavlak and Magdalena Klemun of IDSS—in consultation with other colleagues at both MIT and Tsinghua University in Beijing, China.

Before the Paris climate talks, the researchers brought their message to Washington. In an invited talk at the White House, Trancik presented the research findings to U.S. policymakers, and the message apparently resonated: U.S. negotiators used the report during the talks to encourage agreement to revisit and strengthen commitments every five years; White House statements on the agreement, including the final press release, cited the mutually reinforcing cycle between enhanced mitigation and cost reductions; and the Paris Agreement cited the benefits of investing in emissions reductions early on to drive down the cost of future mitigation.

Understanding technology development

Trancik is not new to the study of technology development. For the past decade, she has been studying the underlying reasons why technologies improve over time. Of particular interest has been figuring out why the cost of a technology falls as its deployment increases—a phenomenon first observed some 80 years ago.

By developing fundamentally new research methods, Trancik has been able to look "under the hood" of solar photovoltaics (PV) and other technologies to model changes over time. The resulting models can be tested against data and then applied to many different technologies to pin down the general drivers of technological improvement. The research has required studying hundreds of technologies, looking for key trends in everything from individual device capabilities and constraints up to macroscale market behavior.

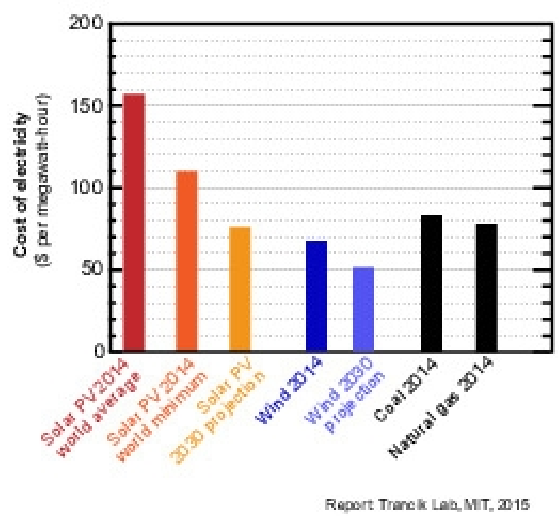

Figure 2: This graph shows current and projected costs of electricity from various sources. The bars represent costs, including contributions from construction and operation, for solar and wind in 2014 and projected costs for

2030 and — for comparison — costs of coal and natural gas in 2014. Despite short-term fluctuations, costs of coal- and natural-gas-based electricity have not exhibited long-term downward trends in recent decades and aren't forecast to do so in the coming decades. (Cost estimates are global averages and do not include energy storage.). Credit: Massachusetts Institute of Technology

About a year ago, she decided to take a comprehensive look at PV and wind technologies—two low-carbon energy sources that have been improving rapidly and have large potential for expansion. Using her analytical methodology, she asked: How quickly are these technologies improving? How rapidly have costs fallen and why? And what can those insights about the past tell us about future trends—in particular, under the emissions-reduction targets stated in the Paris Agreement?

Expanding markets, falling costs

In recent decades, worldwide solar and wind electricity-generating capacities have grown at rates far outpacing experts' forecasts, and associated costs have dropped dramatically. The charts in Figure 1 of the slideshow above show those changes. Between 2000 and 2014, global solar PV capacity increased 126 times and wind capacity 23 times. Over the same period, the price of a solar PV module dropped 86 percent per kilowatt, and the cost of wind-generated electricity dropped by 35 percent per megawatt-hour. (Changes in solar costs cited here are based on module price because the cost of installation varies so widely from country to country.)

Drawing on Trancik's past research on the drivers of technological improvement, the researchers determined why those costs have been falling. Public funding of research and development has played a role, but a key contributor has been the policies enacted by governments worldwide to reward the use of emissions-reducing technologies. Those policies have caused deployment of solar and wind technologies to ramp up and markets to expand, increasing competition among firms to excel. For example, in-house researchers work to improve product designs and manufacturing procedures. Technicians on solar PV manufacturing lines find ways to waste less high-cost silicon and make processes more efficient. And increased output yields cost reductions from economies of scale.

"Policies to incentivize the growth of markets have unleashed the ingenuity of private companies to drive down costs," says Trancik. "I think that's an important angle that's not always recognized."

Interestingly, the gains have resulted from a hodgepodge of public policies adopted by a handful of countries in North America, Europe, and Asia. And the leadership role in installing the technologies has shifted over the past three decades. Solar PV deployment was led by Japan and later Germany, while wind deployment shifted from the United States to Germany and ultimately to China. "Effort was not coordinated," says Trancik. "Nonetheless, something resembling a relay race emerged, with countries trading off the leader's baton to maintain progress as efforts from individual nations rose and fell."

Implications for the Paris Agreement

So what do those insights mean for the future under the Paris Agreement? To find out, the researchers first had to estimate how much solar and wind capacity would be deployed under the Intended Nationally Determined Contributions (INDCs) specified by countries in the Paris Agreement. They assumed a scenario that had a "relatively heavy" emphasis on the renewables but also allowed for expanded use of nuclear fission and hydropower, and they took into account any specific commitment to renewables adoption that countries have made. Based on analyses of all the INDCs, they concluded that global installed solar capacity could increase nearly fivefold and wind about threefold between now and 2030.

To forecast how costs will change at those deployment levels, the researchers used models that Trancik had developed in her previous research, including methods of dealing with inherent uncertainty and forecasting errors so as to generate robust results. In addition, they incorporated expert opinion into their estimates of the "soft costs" of PV installation—that is, labor, permitting, and on-site construction costs, which vary significantly from country to country. Based on their analyses, they forecast a cost decline of 50 percent for solar PV and 25 percent for wind between now and 2030 (and they quantify the expected errors in those forecasts).

Figure 2 in the slideshow above helps to put those costs into context. The bars show electricity costs (including contributions from construction and operation) in 2014 from solar, wind, coal, and natural gas and cost projections for solar and wind in 2030.

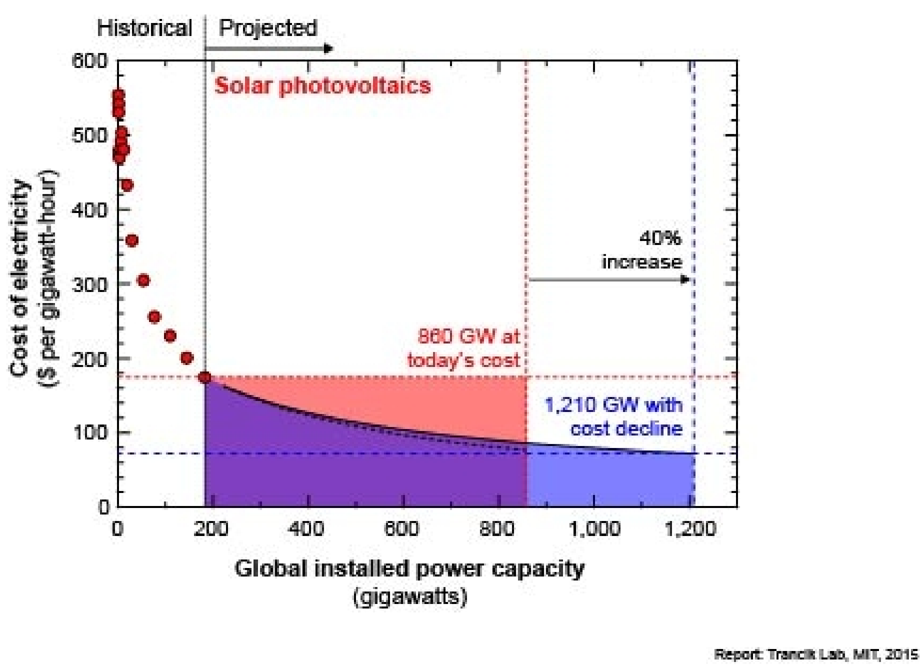

Figure 3: This chart shows cost declines enabling increased deployment without expanded investment. Under the targets in the Paris Agreement, countries will deploy a total of about 860 gigawatts (GW) of solar PV by 2030. Pink shading indicates the total required investment, assuming today's electricity cost. But if costs decline as forecast — as shown by the downward-sloping solid curve — a 40 percent increase in deployment is possible for the same investment (shown by the blue shading). Credit: Massachusetts Institute of Technology

The results show that wind is already competitive with coal and natural gas in 2014. Solar PV can compete only with coal and only when the coal cost is increased to account for health-related costs resulting from air pollution (as estimated in the literature). By 2030, solar costs are roughly comparable to the 2014 coal and natural gas costs, even without considering health costs. "So there are already circumstances under which switching from fossil fuels to renewable sources could both abate carbon emissions and reduce the cost of generating electricity," says Trancik, adding that the "development of storage will become increasingly critical over time as intermittent renewables deployment grows."

Of course, an obvious question is whether the coal and natural gas technologies will also improve between now and 2030, eroding the renewables' ability to compete. According to the researchers, the cost of generating electricity with those fuels hasn't followed long-term decreasing trends in recent decades. In both cases, a large fraction of the total cost is buying the fuel. Those fuel costs tend to fluctuate over the short term but trend neither up nor down over the longer term, limiting the cost decline for the technologies that rely on them.

Messages for policymakers

So what does this mean for international climate change efforts? Trancik cites several possible outcomes for the Paris Agreement if pledges are met. One is that the targets are reached, costs fall, and countries are that much better positioned by 2025 or 2030 to commit to further emissions reductions and expanded adoption of low-carbon technology.

Another possible outcome is that the deployment of wind and solar PV could actually outpace the INDC commitments, either due to market forces alone or because of increasingly aggressive public policy. Policymakers may become more ambitious over time because of the ability to deploy more low-carbon energy without additional financial investment. That possibility is demonstrated in Figure 3 of the slideshow above, which plots global installed solar capacity against the cost of electricity. According to the researchers' scenario, the INDCs commit countries to deploying a total of 858 gigawatts (GW) of solar PV by 2030.

But if costs decline as forecast by the MIT team, then investing the same amount of money could fund the deployment of 1,210 GW—a 40 percent increase. Performing the same analysis for wind shows that the projected cost decline would permit a 20 percent increase in the amount of wind power deployed for the same investment.

"So if developed countries invest their cost savings back into deployment, they could increase their emissions-reduction commitments without changing the total investment—and the larger those commitments, the faster costs may fall," says Trancik. "If good decisions are made, by the time the least-developed nations are required to cut emissions, technology development may have lowered costs so much that switching to low-carbon energy is a benefit rather than a burden."

Sustaining the momentum

As solar PV and wind power begin to dominate electricity markets, other technologies and practices will be needed to ensure reliable delivery of power. Since electricity generation from solar and wind sources is intermittent, ensuring that supply is available to meet demand will require bulk storage devices, expanded long-distance transmission infrastructure, and methods of shifting demand to times of maximum supply. "We can draw lessons on how to drive innovation in those areas by observing the approaches that successfully grew PV and wind markets," says Trancik. But, she notes, the future is uncertain and we shouldn't "put all our eggs in one basket." Other low-carbon electricity sources—such as hydropower and nuclear fission in some locations—as well as technologies for transportation and heating should also be supported.

On the solar side, a final challenge—and opportunity—is to bring down the soft costs of installation. PV modules and inverters are sold in a global marketplace, so cost-reducing advances in that hardware can be shared internationally. But the soft cost components aren't currently traded on global markets, and they're twice as high in some countries as in others. Finding ways to share knowledge and best practices relating to soft costs, or possibly even creating global markets, could significantly reduce total costs, both within some countries and globally.

Trancik and her collaborators offer one last encouraging observation: There appears to be growing recognition among negotiators of the long-term positive contributions their countries can make by supporting low-carbon energy and driving down costs. "I think countries now realize that by supporting the early-stage development of these low-carbon energy technologies, they're helping to contribute knowledge that will last indefinitely and will enable the world to combat climate change, and they take pride in that," says Trancik. "It's something that can become part of their historical legacy—an opportunity that I believe played a role in the latest climate change negotiations."

More information: Technology Improvement and Emissions Reductions as Mutually Reinforcing Efforts: Observations from the Global Development of Solar and Wind Energy. hdl.handle.net/1721.1/102237

Provided by Massachusetts Institute of Technology