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THE DARK SIDE OF SOLAR

How the rising solar industry empowers political interests that could impede a clean energy transition

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Varun Sivaram

Introduction

In recent years, solar power has surged to become the cheapest and fastest-growing source of electricity on the planet. Over the last decade, solar installations have grown annually by over 30 percent on average, thanks to costs that have plunged more than 90 percent. This red-hot growth suggests that in the near future, solar power could challenge fossil fuel dominance and help the world reduce its carbon emissions. As a result, solar power has become the poster child of a putative clean energy revolution.[1]

Yet such a revolution is in fact a long way off. Fossil fuels still supply most of the world's energy needs. Today, solar power provides just 2 percent of the world's electricity, and the generation of electricity, in turn, accounts for just a quarter of the world's greenhouse gas emissions.[2] To avert catastrophic climate change, the world will have to nearly eliminate its emissions shortly after midcentury—a goal known as deep decarbonization—which will require the most ambitious overhaul of the world's energy infrastructure in human history.

The danger is that a broad constellation of increasingly powerful political interests—buoyed by the rise of the global solar industry—might not support the farsighted public policies needed for the world to achieve deep decarbonization. At first blush, this is counterintuitive. The political interests allied with the fossil fuel industry are much more obvious culprits in delaying the shift away from a carbon-intensive energy mix. By contrast, far from thwarting decarbonization, ascendant backers of solar energy would appear to be well placed to further promote solar power and advance a clean energy transition.

That intuitive and happy outcome might indeed come to pass. But there are warning signs that coalitions of

[1] International Energy Agency, "Renewables 2017: Analysis and Forecasts to 2022," (Paris: International Energy Agency, 2017), http://www.iea.org/bookshop/761-Market_Report_Series:_Renewables_2017.

[2] Stephen Lacey, "Global Solar Capacity Set to Surpass Nuclear for the First Time," *Greentech Media*, August 21, 2017, https://www.greentechmedia.com/articles/read/global-solar-capacity-set-to-surpass-global-nuclear-capacity#gs.3wkTQBo; "Global Greenhouse Gas Emissions Data," Environmental Protection Agency, April 13, 2017, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data.

solar advocates might channel some of their political influence toward pressuring governments around the world to enact policies that would make deep decarbonization more expensive and complicated. Such advocacy coalitions—spanning interests from industry, civil society, and political organizations—might appear united in pushing for renewable energy deployment to combat climate change, but actually harbor a variety of political goals that diverge from global decarbonization.

Three examples of public policies that might impede long-term decarbonization—but nonetheless are backed by the solar industry or its political allies—raise concerns about the political power unleashed by solar power's rise. First, in countries including Germany and the United States, some environmental groups are pressuring policymakers to shut down nuclear reactors, even though nuclear energy and another unpopular energy source, fossil fuel plants equipped to capture carbon emissions, are important elements of a pragmatic decarbonization strategy. Second, the U.S. advocacy coalition that once supported both innovation in and deployment of solar energy now mostly supports deployment, content to leave underfunded the innovations needed to harness solar power's full potential. And third, factions of the solar industry across the developed and developing worlds have all lobbied, with some success, for barriers to free trade of solar components, which make it more costly to deploy solar power.

That solar advocates might not push for optimal decarbonization policies is not surprising. Some advocates, such as environmental groups, have a range of goals, such as local environmental protection, that often clash with the imperatives of global decarbonization. And the solar industry, like any other, has its own interests, which it has sought to advance by organizing politically and recruiting a diverse coalition of allies. Yet what is narrowly good for solar power in the short term is not necessarily broadly good for global decarbonization or even, for that matter, the long-term growth of solar power. Indeed, without political support for a more flexible and reliable power grid, for example, the progress of both solar deployment and emissions reductions could stall.

To be sure, the great success of advocacy coalitions in persuading governments to pass policies supportive of solar power has enabled the breakneck growth of the solar industry. Moreover, the support of these coalitions could be important to pass sensible climate policies, such as carbon pricing regimes, that solar advocates generally favor. Therefore, policymakers should aim to harness the increasing political influence of these actors to advance policies conducive to deep decarbonization. At the same time, they should recognize that some suboptimal, inefficient policies are unavoidable and even desirable if they enable a broader policy portfolio that is sensible on balance. For their part, the solar industry and its political allies should look beyond narrow advocacy for near-term solar incentives and back policies to create the flexible, decarbonized energy systems that will enable solar power's long-term success.

The next section of this paper provides a brief history of the solar industry, chronicles the rise of a politically powerful solar advocacy coalition, and explains the potential for a growing divergence between the interests of solar advocates and the goal of global decarbonization. The following section examines three warning signs of such a divergence between the interests of solar advocates and the goal of global decarbonization. Finally, the paper concludes with recommendations to U.S. policymakers, and to advocates.

Background and context

A brief history of the solar industry

For most of its history, the solar industry has been on the outside looking in—only recently has solar power emerged as a mainstream energy source.[3] In 1954, scientists at Bell Labs unveiled the silicon solar photovoltaic (PV) cell, a device that, with no moving parts, could convert sunlight into electricity with an unprecedented 6 percent efficiency. For a brief period, this invention

[3] This paper focuses on the rising political influence of the solar photovoltaic (PV) industry and its allies (rather than also encompassing the solar water heating or concentrated solar power industries) because PV is the globally dominant solar technology.

appeared revolutionary; *The New York Times* crowed that it could lead to "the harnessing of the almost limitless energy of the sun for the uses of civilization."[4] But the timing couldn't have been worse. The prior year, President Dwight Eisenhower had delivered his "Atoms for Peace" speech at the United Nations, setting off a global frenzy to harness nuclear power. As countries rushed to develop and deploy nuclear technology, solar power was largely ignored. For example, during the 1950s, U.S. government funding for solar research and development (R&D) was just $100,000 per year, whereas nuclear power received over $1 billion annually.[5] More generally, the postwar years saw a push by U.S. electric power utilities to scale-up centralized energy generation—including nuclear reactors but also large fossil fuel plants—leaving scant investment available for solar energy, a nascent and more decentralized technology.

As a result, the solar industry scoured remote settings on and off the planet for market opportunities where it would not have to compete with politically favored nuclear power or entrenched fossil fuels. Over the next two decades, solar panels were used to power space satellites, offshore oil platforms, and telecommunications repeaters in the Australian Outback.[6]

In the 1970s, the U.S. solar industry got a brief but short-lived boost when global oil prices spiked. By 1980, Congress had authorized over $1 billion per year in R&D funding and deployment incentives for solar power. Thanks to favorable domestic policy, the United States accounted for 85 percent of the global solar PV market. But America quickly ceded industry leadership when President Ronald Reagan urged lawmakers to slash government support for solar in the 1980s, driving U.S. solar companies out of the market. In the 1990s, Japanese firms took the lead in manufacturing and deploying solar power, thanks to the Japanese government's swelling support for R&D and deployment—driven partly by the country's concerns about energy insecurity and its desire to create a new domestic industry. Next, in the 2000s, Germany had its turn as the global solar industry leader, thanks to landmark legislation that offered substantial incentives for solar deployment. Even though solar power was still substantially more expensive than electricity from fossil fuel or nuclear plants, the German incentive policy—known as a feed-in tariff—guaranteed a premium price for owners of solar installations to sell their power to a utility for the next 20 years, enabling solar power to compete with cheaper sources of energy.[7]

By this point, a half-century after the discovery of the silicon solar cell, solar PV had become a multibillion dollar industry. But it was an industry scarred by boom and bust, and acutely aware that its future success hinged on government support. In each of the countries where it had thrived—first the United States, then Japan, and then Germany—it had done so because of generous government incentives. In the years to come, the industry would go through its biggest upheaval yet as Chinese firms and the Chinese government entered the fray.

Attracted by generous incentives to deploy solar power in developed countries such as Germany, Chinese firms began ramping up production in the 2000s. They were aided by government subsidies for domestic manufacturing, resulting in massive overcapacity spanning from the production of polysilicon (the raw material feedstock) to finished solar panels. Around 2010, European countries, such as Germany and Spain, slashed their subsidies for deploying solar power as they reeled from the Great Recession (in Spain's case, the subsidies were also poorly designed, leading to ballooning costs before their abrupt curtailment).

Combined, production overcapacity and cuts to the subsidies that had fueled demand drove solar producers in China to wage an all-out price war. As a result, panel prices dropped 30 percent just from 2009 to 2010; they fell by half again by 2013, as producers har-

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4 "Vast Power of the Sun Is Tapped by Battery Using Sand Ingredient," *The New York Times*, April 26, 1954, http://www.nytimes.com/packages/pdf/science/TOPICS_SOLAR_TIMELINE/solar1954.pdf.

5 Harvey Strum, "Eisenhower's Solar Energy Policy," *The Public Historian* 6, no. 2 (Spring 1984): 37-50, https://www.jstor.org/stable/3376913.

6 Geoffrey Jones and Loubna Bouamane, "'Power from Sunshine': A Business History of Solar Energy," (Boston: Harvard Business School, May 25, 2012), http://www.hbs.edu/faculty/Publication%20Files/12-105.pdf.

7 Bob Johnstone, *Switching to Solar: What we can learn from Germany's Success in Harnessing Clean Energy* (New York: Prometheus Books, 2011).

Figure 1. Chinese share of solar PV production and deployment.

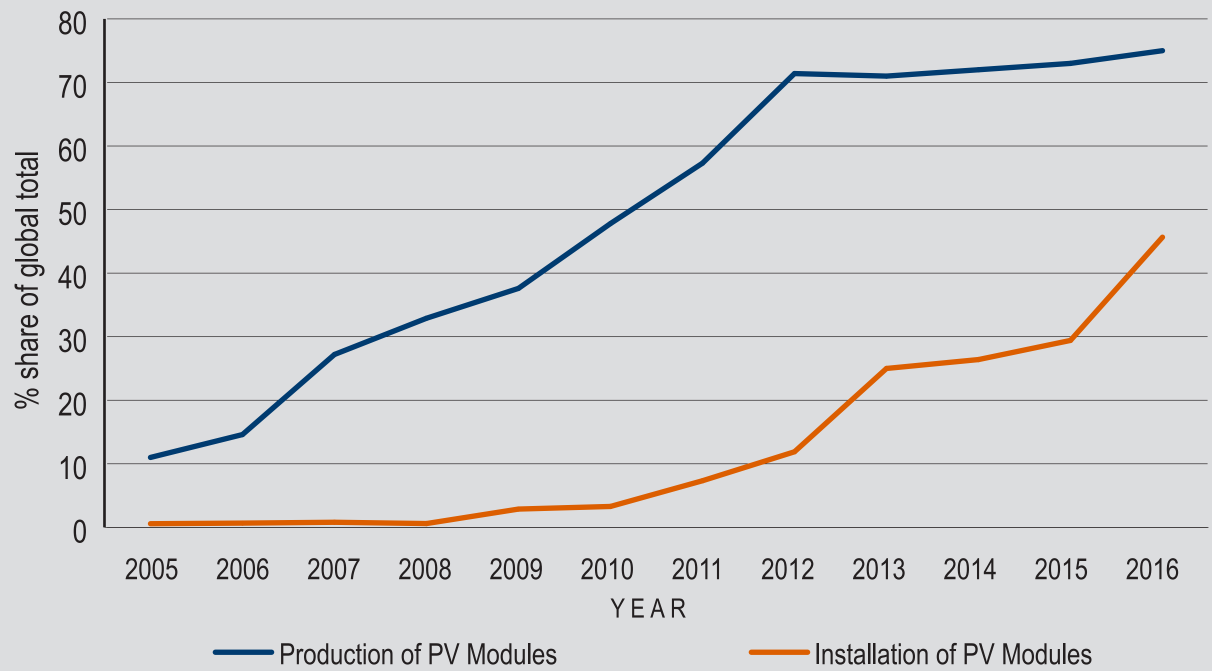

Figure 1 compares China's rising domestic share of global PV module annual production with its more recently rising domestic share of global solar PV annual installations (both measured in gigawatts of power-generating capacity). Note that Chinese production statistics include production in Taiwan, which accounted for roughly 12 percent of global solar PV cell and panel production in 2016.[8]

nessed massive economies of scale and honed their production lines. This drove higher-cost producer firms around the world out of business, from established German manufacturers to well-funded Silicon Valley startups with brand new solar PV technologies—including, perhaps most famously, Solyndra. That firm, backed by U.S. federal subsidies, had developed a technology that would have performed well in a world where polysilicon was expensive and traditional solar cells costly. Instead, with the flood of Chinese production, prices crashed.[9]

When the dust settled, China had become the world's largest manufacturer of solar panels, accounting for over 70 percent of global production by 2012. And as countries abroad cut their subsidies, the Chinese government began shifting from subsidizing the production of solar panels to funding solar deployment at home so its local manufacturers would have a market to sell to. By 2011, China accounted for more than half of global PV production; by 2016, the country installed at home about half of the global production capacity (Figure 1).

A side effect of the Chinese takeover of the solar industry is that innovation in solar PV technology has ground to a halt; Chinese solar firms invest less than 1 percent

[8] For data through 2012, see Nagalakshmi Puttaswamy and Mohd. Sahil Ali, "How Did China Become the Largest Solar PV Manufacturing Country?" (Bengaluru: Center for Study of Science, Technology, and Policy, February 2015), http://www.cstep.in/uploads/default/files/publications/stuff/CSTEP_Solar_PV_Working_Series_2015.pdf. For data after 2012, see Franhofer Institute for Solar Energy Systems, "Photovoltaics Report," (Freiburg: Fraunhofer Institute for Solar Energy Systems, February 26, 2018), http://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf.

[9] John Deutch and Edward Steinfeld, "A Duel in the Sun: The Solar Photovoltaics Technology Conflict Between China and the United States," (Cambridge, MA: Massachusetts Institute of Technology, May 2013), http://energy.mit.edu/wp-content/uploads/2013/05/MITEI-WP-2013-01.pdf.

of their revenues into R&D.[10] True, the performance of solar panels has inched upward as producers gain experience in making them, and a host of complementary innovations have made it easier to finance and deploy solar power. But remarkably, the silicon solar PV technology produced by Chinese firms is not all that different from the original devices invented by Bell Labs in 1954.

To be sure, much is still aligned—technologically and politically—around solar PV. The outlook for the growth of solar power is bright in the coming years. Not only are Asian-manufactured solar panels cheaper than ever, the cost to deploy fully installed solar systems has dropped around the world as firms have gained experience in implementing solar projects. Lazard, an investment bank, reckons that electricity from solar energy is now as inexpensive as that from natural gas and much cheaper than coal power in the United States. Elsewhere, across Asia and Latin America, long-term contracts for solar power have been signed for 2 cents per kilowatt-hour or less, undercutting every other power source (though such rock-bottom headline prices might conceal government support, rising prices over the contract duration, or loss-leading strategies by eager project developers).[11] As a result of falling costs, Bloomberg New Energy Finance predicts that global installed solar capacity could surge by 1,500 percent by 2040, a scenario in which solar power would produce 17 percent of the world's electricity (Figure 2).[12]

Figure 2. Projection for global solar deployment.

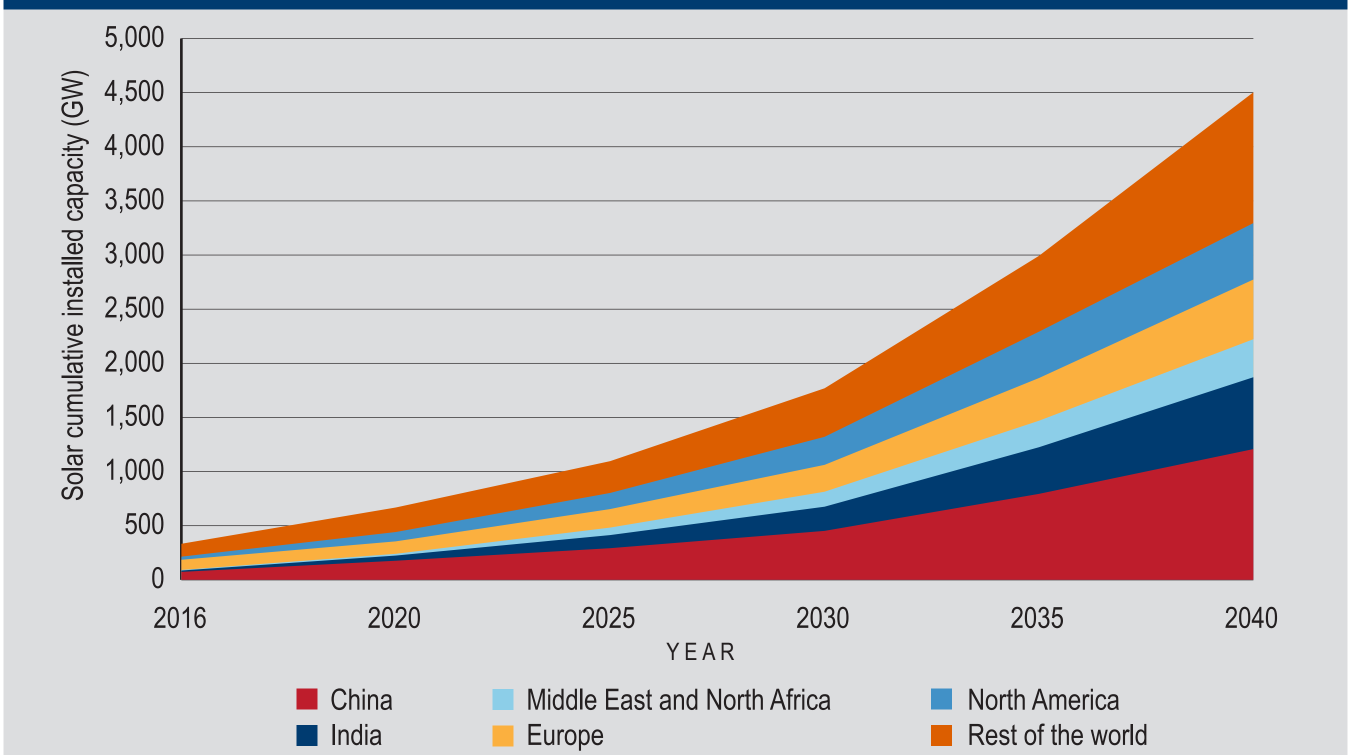

Figure 2 plots the expected growth in the installed solar PV capacity (measured in gigawatts) in major countries and regions around the world between 2016 and 2040.[13]

[10] Jeffrey Ball, Dan Reicher, Xiaojing Sun, and Caitlin Pollock, "The New Solar System: China's Evolving Solar Industry and Its Implications for Competitive Solar Power in the United States and the World," (Stanford, CA: Steyer-Taylor Center for Energy Policy and Finance, Stanford University, March 20, 2017), https://www-cdn.law.stanford.edu/wp-content/uploads/2017/03/2017-03-20-Stanford-China-Report.pdf.

[11] Lazard, "Lazard's Levelized Cost of Energy Analysis – Version 11.0," (New York: Lazard, November 2017), http://lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf; Jason Deign, "Mexican Solar Sets a Record Low Price for Latin America," *Greentech Media*, November 29, 2017, http://www.greentechmedia.com/articles/read/mexican-solar-record-low-price-latin-america.

[12] "New Energy Outlook 2017," Bloomberg New Energy Finance, June 2017, http://bloomberg.com/company/new-energy-outlook.

[13] Ibid.

The growing political clout of solar advocates

Because solar energy has historically been a marginal and expensive power source, its advocates have focused on raising awareness of solar power and securing public subsidies for its advancement. At the same time, the solar industry was too small for its advocacy efforts to be taken very seriously by incumbent energy industries. Suddenly, however, solar power has entered the mainstream, and silicon solar technology is now cheap enough to thrive without subsidies in many settings. Now, as the solar industry grows, so do the number and political clout of its advocates, even though they are no longer united on what exactly to advocate for.

Firms in the solar industry are not the only actors that engage in political advocacy to promote solar power. Rather, there is a whole constellation of actors—including firms in and out of the solar industry, environmental advocates, labor unions, and political parties—that seek to influence the political process and secure policy outcomes favorable to solar power. This collection of actors is known in the academic literature as an "advocacy coalition," which shows "a non-trivial degree of coordinated activity over time."[14]

Advocacy coalitions were instrumental in securing the policy support for solar power that kick-started the industry's current boom. For example, Germany passed its pivotal national feed-in tariff law in 2000 thanks to the efforts of a diverse advocacy coalition. As one notable study of the run-up to the law's passage notes, this was an "unorthodox coalition," comprising "various environmental groups, the two solar industry associations, the association of the machinery and equipment producers VDMA, the metalworkers trade union IG Metall, three solar cell producers, and politicians from some Länder [German states.] … [It] even included a major utility."[15] Thanks to the resulting boom in German solar deployment, the solar manufacturing industry was able to achieve the scale it needed to drive down costs and enable solar energy to compete with fossil fuels across the developed and developing worlds.

But even though the actors in an advocacy coalition are loosely coordinated, they do not necessarily share the same objectives. In Germany, this has manifested in the straining of the advocacy coalition that united around the original feed-in tariff policy, but has splintered over how quickly those incentives should disappear. As solar power has become cheaper, it is less reliant on feed-in tariff incentives. Environmental organizations concerned with reducing greenhouse gas emissions recognized that lower incentives would not compromise their goals while avoiding a high and unpopular price tag for subsidizing the increasing scale of solar power. But Germany's largest solar industry association, BSW, lobbied hard to prop up public incentives. As a result, environmental organizations such as Greenpeace accused the industry of lobbying to pad its profits. As trust among former partners eroded, the advocacy coalition lost some of its political influence.[16] In 2016, Germany largely ended feed-in tariffs in favor of more economical reverse auctions—in which project developers bid to supply solar power at the lowest cost—to drive down renewable energy costs.[17]

In the United States and Japan—the two other countries that incubated the solar industry—diverse advocacy coalitions also emerged to push for favorable public policies toward solar power, though in neither country were they as influential as in Germany. In the United States, coordinated advocacy among environmental groups and renewable energy firms, especially in states such as California, led to policies such as net metering at the state level and the investment tax credit at the federal level to support solar energy's growth from the 1990s onward.[18] Yet there was more political pushback against

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[14] Paul A. Sabatier, "An advocacy coalition framework of policy change and the role of policy-oriented learning therein," *Policy Sciences* 21, no. 2-3 (June 1998): 129-168, http://link.springer.com/article/10.1007%2FBF00136406?LI=true.

[15] Staffan Jacobsson and Volkmar Lauber, "The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology," *Energy Policy* 34, no. 3 (February 2006): 256-276, http://ac.els-cdn.com/S0301421504002393/1-s2.0-S0301421504002393-main.pdf?_tid=269af572-e0ee-11e7-8f82-00000aab0f02&acdnat=1513270100_850f00f050a39db6aa2bcbe64c2340a7.

[16] Wolfgang Gründinger, *Drivers of Energy Transition: How Interest Groups Influenced Energy Politics in Germany* (Berlin: Springer VS, 2016), 371.

[17] Kerstine Appunn, "EEG reform 2016 – switching to auctions for renewables," *Clean Energy Wire*, July 8, 2016, http://cleanenergywire.org/factsheets/eeg-reform-2016-switching-auctions-renewables.

[18] Leah C. Stokes and Hanna L. Breetz, "Politics in the U.S. Energy Transition: Case Studies of Solar, Wind, Biofuels, and Electric Vehicles Policy," *Energy Policy* 113 (February 2018): 76-86, https://www.sciencedirect.com/science/article/pii/S0301421517307322.

solar power—from conservatives and fossil fuel firms—than in Germany, resulting in a less aggressive solar deployment trajectory.[19] In Japan, a diverse solar advocacy coalition also aligned environmental groups with the solar industry, but this coalition was weaker still. Environmental groups have traditionally held little sway over Japanese policymaking, and except for a brief period from 2009 to 2012, a single political party with strong ties to power utilities and limited enthusiasm for renewable energy, the Liberal Democratic Party (LDP), has controlled the national government. Therefore, even though Japan passed a renewable energy law in 2011 that was modeled after Germany's landmark feed-in tariff law, a change in government soon after muted the stimulus to the solar industry.[20]

Nevertheless, the rapid global deployment of solar energy is building its political strength both in countries where the industry has a long history as well as in new theaters of solar growth. In 2016, solar projects attracted over $100 billion globally, and an increasing number of jobs are linked to the solar industry.[21] In the United States, nearly 400,000 people are employed by the solar industry—mostly in the construction of new solar projects—making solar power the largest source of employment in the U.S. electric power sector.[22] A similar number of solar workers are projected to be employed by 2022 in India, as the country progresses toward its target of 100 gigawatts (GW) of installed solar power.[23] Even this deployment target pales in comparison with that of China, which leads the world in both the production and deployment of solar power and employs millions in the industry.[24] There, renewable energy industries are exerting increasing influence on policymaking, for example lobbying for policies to guarantee that new solar and wind power plants will be connected to the grid and paid for their power.[25] Thus, the growing level of solar investment and employment around the world is creating powerful political interests with a stake in the solar industry's continued growth.

The rising political clout of the solar industry and its allies might appear to be an unambiguously positive development. After all, to advance a clean energy transition, solar power will need to challenge formidable fossil fuel incumbents. And, as solar power grows from a mere irritant to a serious competitor, fossil fuel companies are increasingly willing to throw their political weight around to undo public policies that solar advocates fought hard to secure in the first place. The increasing political clout of advocacy coalitions backing solar power provides an important counterweight to such efforts by incumbent fossil fuel firms.

Nevertheless, there is a dark side to the rising political power of solar advocates: the potential for regulatory capture, in which the solar industry and its political allies might lobby governments for policies that narrowly promote solar power without commensurate benefits to society. This is a well-known phenomenon across industries; indeed, elsewhere in the energy sector, powerful industrial interests around the world have lobbied to maintain costly fossil fuel subsidies that can strain government budgets and exacerbate pollution.[26] In the case of solar power, industry lobbying for policies that maximize short-term solar deployment and industry profits might not advance long-term decarbonization. It might not even advance the long-term

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[19] Frank N. Laird and Christoph Stefes, "The Diverging Paths of German and United States Policies for Renewable Energy: Sources of Difference," *Energy Policy* 37, no. 7 (July 2009): 2619-2629, https://www.sciencedirect.com/science/article/pii/S0301421509001189..

[20] Manuela Hartwig, Yohei Kobashi, Sae Okura, Leslie Tkach-Kawasaki, "Energy Policy Participation Through Networks Transcending Cleavage: An Analysis of Japanese and German Renewable Energy Promotion Policies," *Quality and Quantity* 49, no. 4 (July 2015): 1485-1512, https://link.springer.com/article/10.1007/s11135-014-0093-9.

[21] "New Energy Outlook 2017," *Bloomberg New Energy Finance*.

[22] U.S. Department of Energy, "U.S. Energy and Employment Report," (Washington, DC: U.S. Department of Energy, January 2017), http://energy.gov/sites/prod/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report_0.pdf.

[23] Neeraj Kuldeep, Kanika Chawla, Arunabha Ghosh, Anjali Jaiswal, Nehmat Kaur, Sameer Kwatra, and Karan Chouksey, "Greening India's Workforce: Gearing up for Expansion of Solar and Wind Power in India," (New Delhi and New York: Council on Energy, Environment, and Water and Natural Resources Defense Council, June 2017), http://nrdc.org/sites/default/files/greening-india-workforce.pdf.

[24] "China to plow $361 billion into renewable fuel by 2020," *Reuters*, January 4, 2017, http://reuters.com/article/us-china-energy-renewables/china-to-plow-361-billion-into-renewable-fuel-by-2020-idUSKBN14P06P.

[25] Wei Shen, "The Role of Business in Driving and Shaping Renewable Energy Policies in China," (Brighton, U.K.: Institute of Development Studies, January 2016), http://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/8453/ER166_TheRoleofBusinessinDrivingandShapingRenewableEnergyPoliciesinChina.pdf?sequence=1&isAllowed=y.

[26] Gabriela Inchauste and David G. Victor, *The Political Economy of Energy Subsidy Reform* (Washington, DC: World Bank, 2017).

growth of solar energy itself. And if the growing solar industry funds or amplifies historically allied organizations, such as environmental groups that sometimes advocate against sensible climate policies, the political rise of solar power could clash with the imperatives of decarbonization.[27]

Warning signs: Examples of divergence between solar advocacy and global decarbonization

It is not surprising that the goals of solar advocates might diverge from the goal of decarbonizing global energy systems as rapidly, feasibly, and cost-effectively as possible. But it is decarbonization that should ultimately matter most to policymakers around the world. Achieving it will require policies that address the twin market failures slowing the free market from realizing a clean energy transition. First, the social cost of emitting greenhouse gases is a negative externality that polluters do not bear; putting a price on such emissions would make clean energy sources more competitive with dirty ones. Second, private firms undervalue the benefits of R&D, a positive externality that requires government support to realize the full societal benefits of rapid improvements in clean energy technologies.[28]

The policies that solar advocates have supported often fail to address either of these twin market failures and might even set back progress toward decarbonization. Three emerging examples illustrate this point.

1. Exclusion of nonrenewable clean energy sources. Although increasing deployment of renewable energy sources such as solar and wind power is beginning to displace fossil fuels and curb the growth in global emissions, rapid global decarbonization will likely require other clean energy sources to supplement intermittent renewables that cannot supply a constant flow of power. In fact, to ensure the long-term growth of solar power, complementary and flexible sources of power generation, alongside energy storage, will likely be needed. Yet advocates of solar power (not necessarily the solar industry itself, but rather its political allies such as environmental groups) have expressed hostility toward exactly the power sources that could provide clean and flexible energy to enable solar power's continued rise: nuclear reactors and power plants fueled by coal or natural gas but equipped to capture carbon emissions.

For example, in Germany, a pro-renewable, anti-nuclear advocacy coalition has successfully shaped public policy, demonstrating how solar power can thrive even while decarbonization stalls. Germany's pro-renewable policies—notably its feed-in tariff law—have rightly been hailed as a crucial driver of the solar industry's early growth. But in addition to phasing in renewable energy, Germany's energy policies have also been shaped by a drive to phase out nuclear energy, fueled in part by the 1986 Chernobyl and 2011 Fukushima nuclear disasters.[29] Following Fukushima, Chancellor Angela Merkel called for a complete phase-out of nuclear power by 2022. As a result, phasing out nuclear power has become as prominent a goal as reducing greenhouse gas emissions; a survey of policymakers across the political spectrum concluded that those are the top two goals of German energy policy.[30]

This is not to imply that the rise of solar energy is primarily responsible for the decline of nuclear power in Germany—it is not. Long-standing public distrust of nuclear power and its safety record is likely the primary reason for nuclear power's fading prospects. Even so, the advocacy coalition that lobbied for pro-renewable policies has also fanned the flames of anti-nuclear sentiment; one study concludes that it was a coalition of pro-renewable and pro-coal interests that defeated pro-nuclear interests

[27] Michaël Aklin and Johannes Urpelainen, *Renewables: The Politics of a Global Energy Transition* (Cambridge, MA: MIT Press, 2018).
[28] Dani Rodrik, "Green Industrial Policy," *Oxford Review of Economic Policy* 30, no. 3 (October 2014): 469-491, http://drodrik.scholar.harvard.edu/files/dani-rodrik/files/green_industrial_policy.pdf.
[29] Detlef Jahn and Sebastian Korolczuk, "German exceptionalism: the end of nuclear energy in Germany!" *Environmental Politics* 21, no. 1 (February 2012): 159-164, https://www.tandfonline.com/doi/abs/10.1080/09644016.2011.643374.
[30] Fabian Joas, Michael Pahle, Christian Flachsland, and Amani Joas, "Which goals are driving the Energiewende? Making sense of the German energy transformation," *Energy Policy* 95 (August 2016): 42-51, http://www.sciencedirect.com/science/article/pii/S0301421516301719.

and resulted in Germany's current nuclear phase-out policy.[31] And even if solar energy is not to blame for nuclear power's woes to date, solar energy's continued growth (the government aims to produce a third of its energy from solar power by 2050) could increase the political clout of environmental and other allies who could dash any hopes of a nuclear revival.

Yet the nuclear phase-out is a major setback for Germany's attempt to curtail its carbon emissions—the government has already admitted it will miss its 2020 emissions target, which it might well have achieved without shutting down much of its nuclear fleet. Since the 2011 decision to rapidly phase out nuclear power, shutdowns of zero-carbon nuclear reactors have offset most of the gains from increased deployment of solar and wind power. The use of coal power has therefore stopped falling, and as a result, Germany's emissions level has stagnated. That is not the only downside to Germany's energy transition strategy. Some German voters may have chosen the extreme right-wing Alternative for Germany party in the 2017 election because of their frustration that despite the mounting energy bills resulting from subsidies to renewable energy, carbon emissions have not fallen commensurately.[32]

Germany presents the clearest example of an advocacy coalition aligned behind solar power but opposed to a nonrenewable clean energy source. But similar coalitions have lobbied to shut down nuclear reactors around the world. For example, environmental groups in Switzerland campaigned in favor of a successful referendum to phase out nuclear power; in California, they have lobbied the government to shut down the Diablo Canyon nuclear power plant and replace it with renewable energy. (Again, it is not the solar industry that is spearheading opposition to nuclear power, but rather the industry's political allies.)

The Californian example is particularly valuable because it showcases the dangerous expectations that advocates have for renewable energy sources such as solar and wind energy to replace nuclear power. Environmental groups lobbied the utility that owns the Diablo Canyon nuclear reactor, the Pacific Gas and Electric Company (PG&E), to close the facility and replace the nearly 10 percent of California's electricity it generates with renewable energy and energy efficiency measures at lower cost. That plan is flatly unrealistic; it will likely cost much more to replace the plant with renewable energy, and a more cost-effective replacement that relies on fossil fuels will increase emissions relative to keeping the nuclear reactor open.[33] In addition to California, neighboring Arizona offers another example of how renewable energy advocates might jeopardize the future of nuclear power. There, solar industry groups and environmental allies have campaigned for a ballot measure to mandate that the state obtain 50 percent of its electricity from renewable sources by 2030 (excluding nuclear power). Such a goal could imperil the state's overall target of 80 percent zero-carbon energy by 2050 if an influx of mandated renewable energy undercuts the economics of the country's largest nuclear power plant, which is located in Arizona. This exemplifies the tension between the goals of solar advocates and a broader agenda of decarbonization at the lowest possible cost.[34] Indeed, as David Victor and Bruce Jones have written, energy policies that try to force change without accounting for economic and technological realities are unlikely to be successful.[35]

In contrast to the United States and Germany, Japan is an example where the relative balance of political power is less in favor of solar advocates. The ruling LDP prizes energy security and diversity for the island nation, and hence has supported nuclear energy both before and after the Fukushima disaster as a reliable source of

[31] Aleh Cherp, Vadim Vinichenko, Jessica Jewell, Masahiro Suzuki, and Miklos Antal, "Comparing electricity transitions: A historical analysis of nuclear, wind and solar power in Germany and Japan," *Energy Policy* 101 (February 2017): 612-628, http://sciencedirect.com/science/article/pii/S030142151630595X.

[32] Stanley Reed, "Germany's Shift to Green Power Stalls, Despite Huge Investments," *The New York Times*, October 7, 2017, http://nytimes.com/2017/10/07/business/energy-environment/german-renewable-energy.html?_r=0.

[33] Ken Silverstein, "Can the Modern Environmental Movement Save Nuclear Energy in California?" *Forbes*, July 6, 2016, http://www.forbes.com/sites/kensilverstein/2016/07/06/can-the-modern-environmental-movement-save-nuclear-energy-in-california/#6a56149b4785.

[34] Darrell Proctor, "Regulators, Lawmakers Spar over Arizona Renewable Mandates," *Power*, March 15, 2018, http://powermag.com/regulators-lawmakers-spar-over-arizona-renewable-mandates/?pagenum=2.

[35] David G. Victor and Bruce D. Jones, "Undiplomatic action: A practical guide to the new politics and geopolitics of climate change," (Washington, DC: Brookings Institution, February 2018), https://www.brookings.edu/wp-content/uploads/2018/02/undiplomatic-action-final.pdf.

domestic energy. That view is in line with that of the politically powerful electric utilities, which strongly favor nuclear energy. Yet the future of nuclear power is not assured even given the favorable politics of Japan. During the brief period from 2009 to 2012 in which the LDP lost government control to the opposition party, the government set in motion plans to phase out nuclear energy and ramp up renewables, inspired in part by Germany and prompted by pro-renewable and environmental groups. Then the Fukushima disaster struck, and the country shut down all of its nuclear plants for safety checks. Even though the LDP promptly returned to power in 2012 and reversed the nuclear phase-out, most reactors remain closed and grassroots resistance to reopening them is strong. Especially as solar energy grows in capacity and political clout, electric utilities in the future may lose their ongoing battle to restart Japan's nuclear fleet.[36]

Nuclear power is not the only clean energy source under fire from solar advocates. Across Europe and the United States, environmental groups and research institutions have warned that a major push to invest in carbon capture and sequestration (CCS) facilities could perversely incentivize the construction of new and polluting fossil fuel plants. Not all environmental groups oppose nuclear power and CCS; some moderate elements have offered qualified support, recognizing that nuclear energy and fossil fuels already produce most of the world's energy, so a clean energy transition that leverages them is far more feasible than one that does not.[37] Nevertheless, as the growing solar industry looks for political allies, firms are unlikely to alienate the most strident environmental voices. As a result, the rise of solar energy could continue to empower political interests eager to cut off important clean energy options.

2. Deployment of existing solar technology, locking out emerging technologies.

By midcentury, solar power could be the largest source of global electricity generation. Yet existing solar PV technology, based on silicon solar panels, may not suffice to achieve that target, because its cost is not falling fast enough to compensate for the tremendous volatility and disruption to the power grid that large-scale global solar deployment would cause. As a result, new solar technologies that are far cheaper—and could unlock brand new market segments by virtue of being flexible, semitransparent, and lightweight—are important to help solar power achieve its potential.[38]

However, the solar industry and its political allies are not very interested in solar innovation. Instead, they are focused on securing policies favorable to the deployment of existing technology. In the United States, solar advocates have successfully lobbied for public incentives to deploy solar power that have sharply risen in value, even while funding for innovation has gently declined. This is especially worrying because the United States has historically been the global leader in energy innovation, so its retreat from supporting advanced solar technologies jeopardizes global prospects for solar innovation.

The U.S. solar industry has always prized the deployment of solar power, but the recent industry shift away from upstream production and toward downstream deployment has intensified its deployment-focused lobbying. In the lead-up to Congress' passage of the 2005 Energy Policy Act, the solar industry association urged public funding for both solar deployment and R&D.[39] In that era, firms still believed that there was substantial technological progress to be made, and that government funding for applied R&D projects would seed the pipeline with new inventions to be further developed by the private sector. Over the following decade, however, the U.S. solar industry's interest in innovation waned. A spate of innovative solar start-ups went bankrupt, unable to compete with the flood of cheap Chinese silicon solar panels, and venture capital investors fled the sector. The balance of upstream and downstream firms also shifted sharply toward downstream solar deployment—by 2016, over 80

[36] Shun Deng Fam, Jieru Xiong, Gordon Xiong, Ding Li Yong, Daniel Ng, "Post-Fukushima Japan: The Continuing Nuclear Controversy," *Energy Policy* 68 (May 2014): 199-205, http://www.sciencedirect.com/science/article/pii/S0301421514000196.

[37] Wolfgang Gründinger, *Drivers of Energy Transition*, 371.

[38] Varun Sivaram and Shayle Khan, "Solar Power Needs a More Ambitious Cost Target," *Nature Energy* 1 (April 2016), http://nature.com/articles/nenergy201636.

[39] Leah C. Stokes and Hanna L. Breetz, "Politics in the U.S. energy transition: Case studies of solar, wind, biofuels and electric vehicles policy," *Energy Policy* 113 (February 2018): 78-86, http://sciencedirect.com/science/article/pii/S0301421517307322.

Figure 3. Comparison of federal funding for solar deployment and innovation.

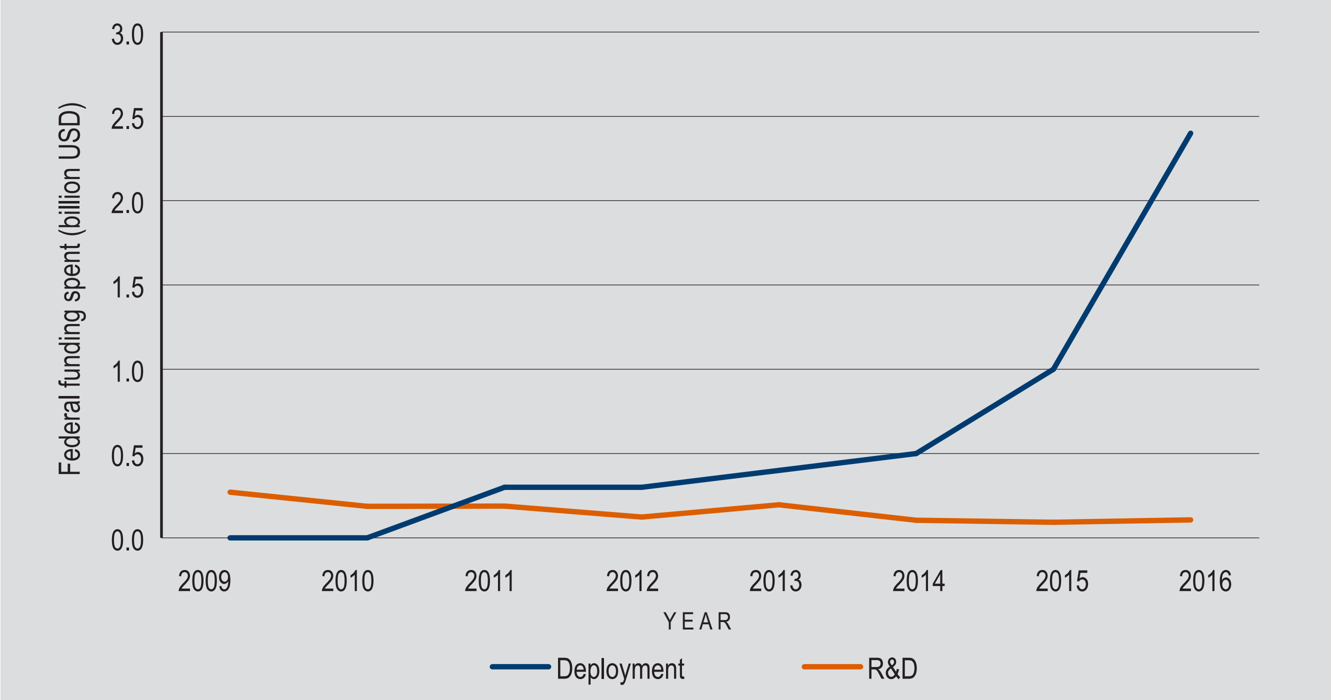

Figure 3: The blue line represents spending on the largest deployment incentive for solar power in the United States, the federal investment tax credit. The orange line represents R&D spending by the Department of Energy, the largest federal funder of solar innovation. Expenditures less than $50 million are counted as $0.[40]

percent of all U.S. solar jobs were in the deployment of solar projects.

In 2015, the solar industry lobbied intensely for an extension of the largest federal deployment incentive: tax credits for investments in solar projects. The industry gained support from an advocacy coalition including strident environmental groups, and ultimately succeeded in convincing congressional Democrats to secure an extension of the tax credits in exchange for supporting an end to the ban on crude oil exports, a core Republican priority.[41] As a result, solar deployment incentives have rocketed upward in value even as support for innovation has declined. Figure 3 compares spending on the largest deployment incentive—the federal investment tax credit that was extended in 2015—with R&D funding from the largest federal funder of solar innovation, the Department of Energy.

As U.S. solar deployment grows, the industry will only lobby harder for further deployment incentives. With no politically powerful advocate, technological innovation is likely to continue to take a back seat to deployment. In other sectors, deployment policies have at least tried to support next-generation technologies; for example, the U.S. Renewable Fuels Standard mandated the use of biofuels, but included special mandates for next-generation technologies alongside first-generation corn ethanol (this policy, however, has been ineffective at spurring production of advanced biofuels).[42] Yet on

[40] "Publications on Tax Expenditures," The Joint Committee on Taxation, Congress of the United States, https://www.jct.gov/publications.html?func=select&id=5; Richard Schmalensee et al., "The Future of Solar Energy," (Cambridge, MA: Massachusetts Institute of Technology, 2015), https://energy.mit.edu/wp-content/uploads/2015/05/MITEI-The-Future-of-Solar-Energy.pdf.

[41] Ibid.

[42] Hanna L. Breetz, "Fueled by crisis: U.S. alternative fuel policy, 1975-2007," (PhD diss., Massachusetts Institute of Technology, February 2013), http://hdl.handle.net/1721.1/83759.

solar power, policies such as the investment tax credit at the federal level or renewable portfolio standards at the state level have no such carve-outs to incentivize the use of emerging, rather than mature, technologies. This omission is partly due to the apathy toward innovation of the solar industry and its advocates, who have furiously lobbied for deployment policies.

Even worse, public policies that incentivize deployment can actually set back innovation by making existing technologies even more dominant and resistant to competition from emerging technologies—a phenomenon known as technology lock-in.[43] Such lock-in might not set back the near-term growth of solar power, because silicon solar technology has proven affordable when there is not very much of it connected to a power grid. But at higher penetration levels, today's technology might prove insufficiently cheap or versatile to keep growing, and when that becomes apparent in the coming decades, underinvestment in new technologies might have prevented successor technologies from reaching commercial readiness.[44]

3. Trade protectionism that raises the cost of clean energy.

Solar power's falling cost has been crucial to its rapid ascent, and is thanks in large part to the increasing scale of the global industry's production of solar panels and their components. But in countries in both the developed and developing world, solar industry factions as well as allies of the industry—such as organized labor—have advocated for barriers to the free trade of solar panels and components, even though such barriers raise the cost of solar power and slow its deployment. Around the world, a similar pattern has recurred: domestic political interests seek to claw back as much value as possible from the growing and globalized solar industry. In China, this manifested as domestic companies securing government subsidies to scale-up production and export panels around the world. And then, in response, the rest of the world is tempted to erect trade barriers to capture some of the economic benefits of local manufacturing, again spurred on by domestic political interests. Yet a world riddled with trade barriers would certainly slow the pace of solar deployment and arrest decarbonization.

The United States was the first country to use aggressive trade policy to try and wrest back solar production market share from China, and a diverse advocacy coalition allying labor and environmental interests pushed through those trade barriers. Labor unions, led by the steelworkers' union, complained to the Obama administration in 2010 about Chinese government support for green technologies including the solar power industry. And a coalition of U.S. solar manufacturers lobbied the government to enact tariffs on imported solar cells and panels to countervail China's below-cost dumping of those products on global markets. This protectionist advocacy coalition succeeded twice, securing tariffs first on Chinese imports in 2012 and then on Taiwanese solar imports in 2014 (after the solar industry complained that Chinese manufacturers were outsourcing production to Taiwan to skirt the trade barriers). As a result, the cost of solar modules rose by up to 20 percent.[45]

Importantly, the solar industry was far from united on these disputes. In fact, most firms in the industry joined a competing coalition that lobbied against the tariffs that a small group of solar manufacturers lobbied for. Firms specializing in the downstream development and installation of solar projects opposed tariffs because higher prices would hinder their ability to deploy solar power, and firms selling equipment and raw materials opposed tariffs that might reduce demand from dominant Chinese manufacturers of solar cells and panels for upstream products. Even a U.S.-headquartered manufacturing firm that split its operations between the United States and China opposed the tariffs (however, this firm—Suniva—is behind the most recent petition for tariffs, discussed below). The only firms that

[43] Joern Hoppmann, Michael Peters, Malte Schneider, and Volcker H. Hoffmann, "The two faces of market support—How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry," *Research Policy* 42, no. 4 (May 2013): 989-1003, http://www.sciencedirect.com/science/article/pii/S0048733313000073; Gregory F. Nemet, "Demand-pull, technology-push, and government-led incentives for non-incremental technical change," *Research Policy* 38, no. 5 (June 2009): 700-709, http://www.sciencedirect.com/science/article/pii/S0048733309000080.

[44] Varun Sivaram, "Unlocking Clean Energy," *Issues in Science and Technology* 33, no 2. (Winter 2017): http://issues.org/33-2/unlocking-clean-energy/.

[45] Llewelyn Hughes and Jonas Meckling, "The politics of renewable energy trade: The US-China solar dispute," *Energy Policy* 105 (June 2017): 256-262, https://www.sciencedirect.com/science/article/pii/S0301421517301283.

supported the trade barriers were U.S. firms with exclusively domestic manufacturing facilities.[46]

Nevertheless, the small group of protectionist interests in the solar industry prevailed, in no small part because of the way that trade decisions are made by the U.S. government. First, it is startlingly easy for U.S. firms to seek trade barriers under U.S. law and for those barriers to be enacted, regardless of any economy-wide damage to the United States that would result. Second, disputes such as the solar trade cases can play out against a backdrop of a larger set of issues, such that the decision on the trade case is not made exclusively on its merits. For example, one reason the Obama administration permitted the solar tariff petition to be investigated in the first place was the administration's desire to secure "fast-track authority" to negotiate the Trans-Pacific Partnership, which it hoped would be its signature trade deal. Senator Ron Wyden (D-OR) was willing to support the president's trade authority but wanted the administration's support to protect solar manufacturing jobs in the senator's home state of Oregon.[47]

The United States was not alone in pursuing trade barriers against China. The European Union (EU) pursued its own investigation into Chinese dumping of solar products and imposed countervailing duties in 2013. To head off a trade war, the EU and China subsequently negotiated a settlement under which Chinese producers would voluntarily honor a minimum selling price and maximum export quantity for solar modules.[48]

Protectionism has not been limited to developed countries. In India, the central government set an ambitious set of deployment targets in 2009 known as the "National Solar Mission." Those targets included a requirement that a portion of the solar projects use locally produced components, thanks to the lobbying efforts of firms such as Moser Baer and Tata Solar, which had invested in domestic manufacturing plants.[49] The United States would later secure a World Trade Organization ruling that this policy was illegal; the dispute continues to be argued in international courts.[50]

India's decade-long quest to enact barriers that contravene international trade law is a harbinger of conflicts to come between the international trade regime and domestic economic policies. Governments benefit politically from promising to create domestic jobs and stimulate economic growth, but the cheapest way to deploy solar power is not to produce solar products at home but rather to import them from China.[51] As Figure 4 demonstrates, China dominates the manufacturing of all solar PV components (the bars measure the value added from manufacturing, which roughly corresponds to the revenues raised from selling manufactured products). Figure 4 also reveals that the United States retains a far higher percentage of value added in its domestic economy—that is, even though its global share of PV manufacturing is far lower than China's, each unit of production contributes much more to the U.S. economy, through wages to workers, payments to domestic suppliers, and government revenue, than a unit of Chinese production contributes to the Chinese economy. As a result, U.S. policymakers may be tempted to support domestic manufacturing and create local jobs, despite the increase in the cost of solar power relative to a baseline of free trade.

This temptation was most recently on display in the United States over the last year, when two struggling solar manufacturers—Suniva and Solarworld—petitioned the Trump administration to enact sweeping tariffs on solar imports not just from China and Taiwan, but

[46] Jonas Meckling and Llewelyn Hughes, "Globalizing Solar: Global Supply Chains and Trade Preferences," *International Studies Quarterly* 61, no. 2 (June 2017): 225-235, http://academic.oup.com/isq/article-abstract/61/2/225/3813359.

[47] Llewelyn Hughes and Jonas Meckling, "The Politics of Renewable Energy Trade."

[48] Yu Chen, "EU-China Solar Panels Trade Dispute: Settlement and challenges to the EU," (Brussels: European Institute for Asian Studies, June 2015), http://www.eias.org/wp-content/uploads/2016/02/EU-Asia-at-a-glance-EU-China-Solar-Panels-Dispute-Yu-Chen.pdf.

[49] Chetan Krishna, Ambuj D. Sagar, and Stephen Spratt, "The Political Economy of Low-carbon Investments: Insights from the Wind and Solar Power Sectors in India," (Brighton, U.K.: Institute of Development Studies, January 2015), http://www.ids.ac.uk/publication/the-political-economy-of-low-carbon-investments-insights-from-the-wind-and-solar-power-sectors-in-india.

[50] Tom Miles, "U.S. takes India back to WTO in solar power dispute," *Reuters*, December 20, 2017, http://reuters.com/article/us-usa-india-wto/u-s-takes-india-back-to-wto-in-solar-power-dispute-idUSKBN1EE1BK.

[51] Joanna I. Lewis, "The Rise of Renewable Energy Protectionism: Emerging Trade Conflicts and Implications for Low Carbon Development," *Global Environmental Politics* 14, no. 4 (November 2014): 10-35, http://mitpressjournals.org/doi/full/10.1162/GLEP_a_00255.

Figure 4. Value added from manufacturing of solar PV products in key countries.

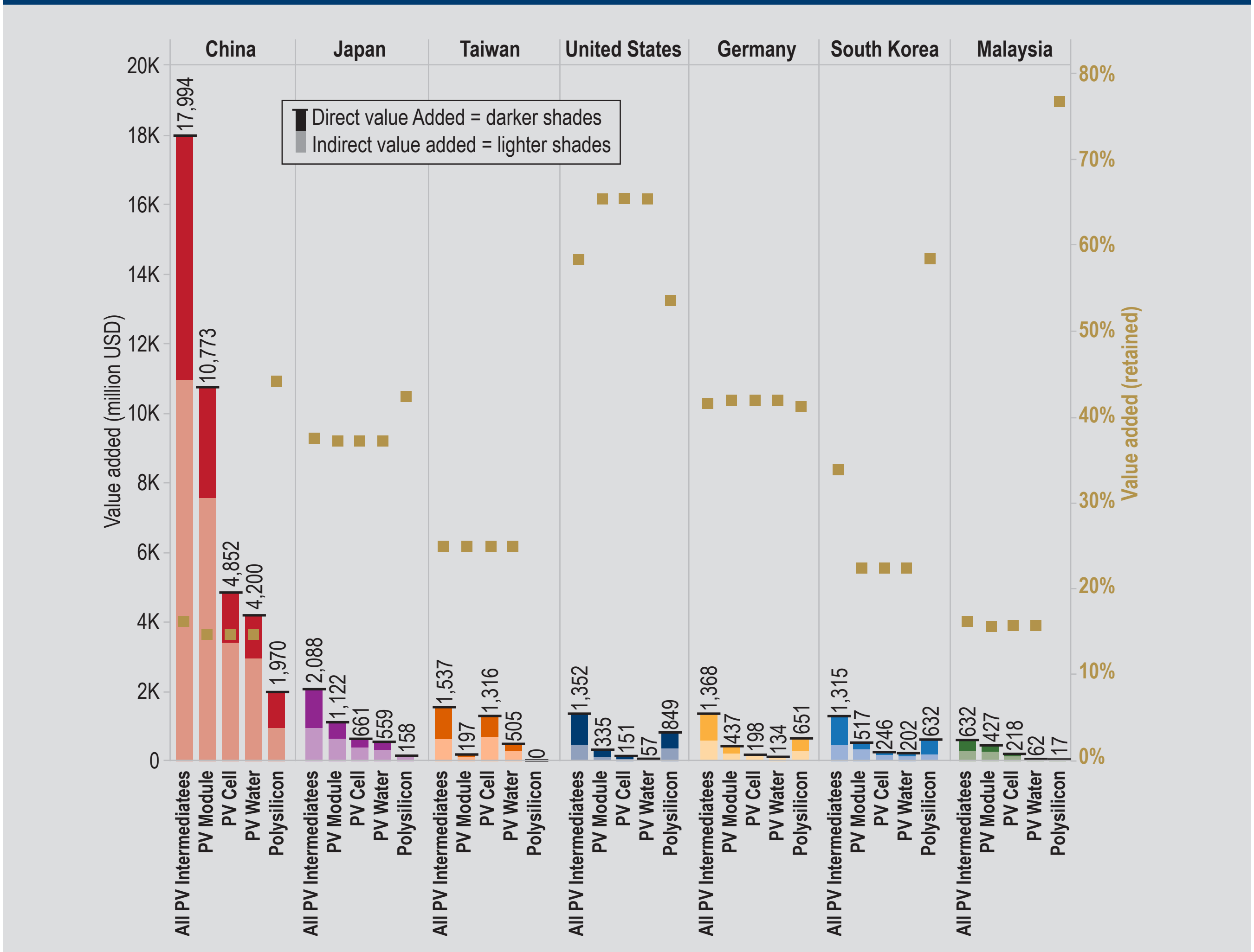

Figure 4: The bars (left y-axis) measure the value added from manufacturing of solar PV modules and their components across seven countries in 2014. The gold squares (right y-axis) measure how much of that value added was retained by a domestic economy.[52]

from nearly every country in the world (notably including Southeast Asian countries such as Malaysia and the Philippines, where solar production has recently ramped up). The Trump administration largely agreed with the petition and enacted sweeping tariffs in January 2018, which could reduce domestic deployment of solar PV by 10 percent over the next five years.[53] Even though the vast majority of U.S. solar jobs are in the installation and deployment of solar PV, and nearly all solar companies opposed the tariffs, the two manufacturers that brought the petition prevailed, possibly because the Trump administration perceived that protectionist policies would be domestically popular.

As countries around the world ramp up their deployment of solar power, new protectionist measures are likely. Already, factions of the solar industry and their political allies, such as labor unions, have successfully

[52] Debra Sandor, Donald Chung, David Keyser, Margaret Mann, and Jill Engel-Cox, "Benchmarks of Global Clean Energy Manufacturing," (Golden, CO: Clean Energy Manufacturing Analysis Center, 2017), https://www.nrel.gov/docs/fy17osti/65619.pdf.

[53] Varun Sivaram, "How U.S. Tariffs Will Hurt America's Solar Industry," *The New York Times*, January 24, 2018, http://nytimes.com/2018/01/24/opinion/tariffs-us-solar-clean-energy.html.

lobbied developed country governments to enact barriers to the free trade of solar PV products. As protectionist advocacy coalitions emerge in developing countries, where solar deployment is forecast to surge in coming years, those governments are also liable to enact such trade barriers. The result could be higher solar prices around the world and a slower rate of solar adoption. That, plainly, would be a setback for efforts to decarbonize the world's energy mix.

Recommendations for U.S. policymakers

Although the rising clout of the solar industry and its allies might result in some suboptimal policy outcomes, solar power's political rise can, on balance, be a positive force for rapid global decarbonization. Recall that optimal decarbonization policies will address two market failures: the failure to price carbon at its social cost and the underinvestment in innovation by the private sector. The rising political power of solar advocates might help policymakers address the first market failure. One optimistic study concludes that early suboptimal policies—such as inefficient subsidies for solar deployment—can build the strength of a political coalition that will ultimately support broader and more efficient regulations, such as an economy-wide price on carbon.[54] Such an outcome could bring societal benefits that outweigh the costs from rent-seeking behavior by the solar industry.

Still, policymakers should not simply wait for increasingly powerful solar advocates to focus their political clout on securing an optimal carbon price sometime in the distant future. There are several steps policymakers can take to mitigate misdirected advocacy as well as address the second market failure—underinvestment in innovation. Although global decarbonization will depend on action from governments around the world, this section focuses on how U.S. policymakers in particular can set an example for how to pursue sensible policies against a backdrop of solar advocates' increasing political clout.

A good place to start is by combating protectionism. The success of a tiny faction of the U.S. solar industry in securing trade barriers—over the objections of the majority of the solar industry—is less a triumph of advocacy coalitions and more a failure of U.S. policymakers to act sensibly. For example, the Trump administration could easily have declined to permit the petition brought by two insolvent solar manufacturers to the International Trade Commission under the rarely-invoked Section 201 of the 1974 Trade Act. But rather than heed the advice of the vast majority of the solar industry as well as analysts and firms across the political spectrum that warned of job losses, stalling solar deployment, and limited succor to far-gone U.S. manufacturers, the administration chose to move forward and enact sweeping tariffs. Its hands were not tied by political interests; rather, the administration chose to pursue an unpopular and imprudent policy.

In general, however, U.S. law does make it particularly easy for aggrieved firms to bring trade petitions. Ideally, Congress would pass legislation making it more difficult to bring such cases or raising the standard under which the executive branch can justify erecting trade barriers. For example, executive action to protect an industry should pass an overall cost-benefit test demonstrating that a trade barrier generates benefits that outweigh the costs to the overall economy. Congress is unlikely to pass such legislation, however, so the gatekeeper role to swat away ill-conceived trade petitions will remain under the president's purview. As solar deployment rises in the United States, political interests will increasingly support free trade; the president should therefore have an even easier time denying petitions to erect trade barriers.

It will be tougher for policymakers to neutralize solar advocates' hostility to nonrenewable sources of clean energy. Anti-nuclear sentiment, though not as pronounced in the United States compared with Europe, is still common among environmental advocates whose political support the solar industry has turned to on several occasions. Nevertheless, even though one

[54] Jonas Meckling, Nina Kelsey, Eric Biber, and John Zysman, "Winning coalitions for climate policy: Green industrial policy builds support for carbon regulation," *Science* 349, no. 6253 (September 11, 2015): 1170-1171, http://igs.berkeley.edu/sites/default/files/science_winning_coalitions_for_climate_policy.pdf.

segment of solar energy's advocacy coalition might oppose nuclear power, the solar industry itself and many of its more moderate allies are not intrinsically opposed to nuclear power. So far, the Trump administration has been exceedingly clumsy in its attempt to support nuclear power. A proposed policy from Energy Secretary Rick Perry would pay nuclear and coal power plants to stay in business, but by tying clean nuclear together with dirty coal, the administration has inflamed environmental advocates and pitted rising renewable energy industries, along with oil and gas interests, against nuclear power.

So long as U.S. decarbonization policy is accomplished through a patchwork of state and federal regulations, public policy will be heavily shaped by political interests. For example, in several states, utilities and solar advocates have clashed on net metering policies and renewable portfolio standards, and the outcome is a highly uncertain policy environment (on top of this, the policies in question, such as net metering, are suboptimal tools to reduce emissions and fund clean energy). A national carbon price is a more economically optimal way to correct the market failure of unpriced carbon and to encourage emissions reductions irrespective of source. Such a policy, however, is unlikely in the current political climate.

An out-of-the-box strategy might be to co-opt the rising political influence linked with the solar industry by tying together the fortunes of solar and nuclear power. The two sources are not necessarily substitutes; rather, a thriving nuclear power sector can complement the rise of intermittent solar power. Nuclear reactors can ramp up and down to smooth out fluctuating solar output—in fact, reactors are used in such a load-following manner in France routinely.[55] Thus, retaining flexible nuclear capacity is one of the many strategies (energy storage, grid expansion, and demand response might be others) needed to accommodate a high penetration of solar power. Fossil fuel power plants equipped with CCS capabilities could also enable a high penetration of solar power—just as natural gas plants currently help stabilize the grid—while reducing carbon emissions. U.S. power markets today are not set up to compensate plants for such flexibility benefits—nuclear reactors have therefore suffered recently, and little incentive exists to build new CCS facilities. Energy-only wholesale power markets have caused nuclear reactors to lose revenue, as increased renewable energy penetration drives wholesale prices; where available, capacity markets (for example, in the regional transmission organization PJM) have not provided the required revenue for nuclear reactors to stay in business.

Federal and state policymakers should collaborate to consider sweeping changes to power market design. For example, some scholars have suggested splitting wholesale energy markets into two, in order to insulate flexible and intermittent resources from destructive competition. The first market would be for on-demand, or firm, power from plants whose output can be reliably controlled. The other market would be for variable power from unpredictable sources, such as solar and wind, which cannot guarantee their output.[56] The difference in prices between the two markets, which energy analyst Michael Liebreich has dubbed the "Firm Spread," will rise as more intermittent renewable energy comes online and flexible resources become more valuable.[57] This idea might not be the exact optimal reform, but it is a creative first step at reimagining power markets with the goal of affordable decarbonization in mind. And as a happy side benefit, the political interests of the rising solar industry would then better align with the goal of incentivizing a thriving fleet of nuclear and other flexible plants to keep solar energy's market revenues from nosediving. The solar industry might then choose to back nuclear power, rather than align itself with anti-nuclear political allies.

For their part, the solar industry and its political allies should shift from their historical advocacy for policies that directly benefit solar energy in the near term to

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[55] Arnulf Grubler, "The Costs of the French Nuclear Scale-Up: A Case of Negative Learning by Doing," *Energy Policy* 38, no. 9 (September 2010): 5174-5188, doi:10.1016/j.enpol.2010.05.003.

[56] Malcolm Keay, "Electricity Markets Are Broken—Can They Be Fixed?" (Oxford: Oxford Institute for Energy Studies, January 2016), https://www.oxfordenergy.org/wpcms/wp-content/uploads/2016/02/Electricity-markets-are-broken-can-they-be-fixed-EL-17.pdf.

[57] Michael Liebreich, "Six Design Principles for the Power Markets of the Future," *Bloomberg New Energy Finance*, May 14, 2017, https://data.bloomberglp.com/bnef/sites/14/2017/05/Liebreich-Six-Design-Principles-for-the-Power-Markets-of-the-Future.pdf.

instead push for a flexible electricity system that can enable solar power's long-term success. In Illinois and New York, some environmental groups have backed policies aimed at preventing the shutdown of existing nuclear reactors.[58] Going forward, solar advocates should recognize that a decarbonized electricity system will likely require CCS options, some of which are more conducive than others to integrating intermittent renewable energy into the grid. In particular, technologies that have a higher ratio of variable to fixed costs, such as Allam cycle gas turbines that capture carbon dioxide for subsequent utilization and storage, are more economically optimized for modulating their power output to supplement renewable output, compared with other technologies with higher capital costs.[59] Rather than opposing all use of fossil fuels, solar advocates could ensure that policy support for CCS technologies is guided by the goal of integrating renewable energy. Finally, the solar political advocacy coalition should proactively advocate for a range of other upgrades to the electricity system that would enable a high penetration of intermittent renewables. These include expanding electricity grids through market expansion and long-distance transmission lines, adding storage to the grid, and increasing the flexibility of customer demand by promoting dynamic electricity pricing and integrating smart infrastructure on both sides of the meter.[60]

Finally, U.S. policymakers must step up to fill the innovation void left by the solar industry's apathy toward R&D—this is just as important (and perhaps more tractable) a market failure to solve as the mispricing of carbon. Fortunately, the solar industry and most of its political allies do not actively oppose investments in R&D and demonstration of new technologies. Therefore, the federal government has an opportunity to sharply ramp up funding for innovation. The Trump administration should expand the budget for the Advanced Research Projects Agency-Energy (ARPA-E), which funds long-term, risky scientific bets; it should increase funding for applied R&D through the Department of Energy, National Science Foundation, and other agencies, and it should invest in the demonstration and early procurement of emerging technologies that otherwise cannot gain market traction owing to the dominance of silicon solar panels.[61] Unfortunately, the Trump administration's first budget proposed nearly the exact opposite of these recommendations, aiming to slash funding for renewable energy R&D and eliminate ARPA-E. Thankfully, Congress ignored Trump's recommendations; in subsequent years, it should continue to increase funding for energy innovation.

The high and rising federal spending on solar deployment, primarily through the investment tax credit, is not ideal for avoiding technology lock-in. However, policymakers should recognize that the increasingly powerful solar industry and its political allies prize this subsidy and will fight against its rollback. Better, then, to leave the subsidy intact (though Congress certainly should not extend the subsidy after its current expiration date in 2022) and continue to recruit the solar advocacy coalition's assistance in passing comprehensive climate legislation, such as a carbon price.

Such a strategy—picking the right battles and recognizing that some inefficient or suboptimal policies are unavoidable in a democracy that empowers political interests—is the right way for policymakers to take advantage of solar power's rising political star. The rise of solar power is a promising step forward in the battle against climate change—deft policymakers can ensure that this step leads down the path of rapid and dramatic global decarbonization.

[58] Keith Goldberg, "Green Groups Back Illinois Nuclear Plant Subsidies," *Law360*, April 13, 2017, http://law360.com/articles/913331/green-groups-back-illinois-nuclear-plant-subsidies; Marie J. French, "Nuclear power subsidy splits New York environmentalists," *Politico*, October 12, 2016, http://politico.com/states/new-york/albany/story/2016/10/nuclear-power-subsidy-splits-new-yorks-green-groups-106279.

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