Lessons from Renewable Energy Diffusion for Carbon Dioxide Removal Development

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ABSTRACT

To avoid dangerous climate change, society will need to deploy carbon dioxide removal technologies (CDR), quite probably in large quantities. Nevertheless, these technologies are undeveloped and currently deployed at only fractions of the amount that will be necessary. Thus, we need to establish a set of policies that will accelerate the development and deployment of CDR.

Patterns of technology diffusion provide important insight into the development of effective policies to promote the innovation and installation of new technologies. The dissemination of new technologies tends to follow a recurring pattern called the S curve. This pattern includes a slow initial adoption, a take-off phase, and then slow dissemination to the remaining population. Recently, experience with the development of renewable energy followed this pattern. Renewable energy's growth not only demonstrates this diffusion pattern, it reveals the effectiveness of certain policies that promoted diffusion. It also illustrates the difficulties that can arise when policies do not match a technology's location on the S curve.

This paper will consider the possible effectiveness of these policies in developing carbon dioxide removal technologies. In an earlier paper, I looked at renewable portfolio standards (RPSs), which mandate quantities of renewables, as a means to incentivize deployment. Accordingly, this paper will focus on price regulations, typically in the form of price subsidies (FITs) or tenders (competitive auctions). It also considers secondary policies – primarily tax credits and cash grants – that enhanced the effectiveness of the primary policy.

This review of renewable energy diffusion and the policies that supported it helps to construct a set of principles and policies that can accelerate the diffusion of CDR technologies. These policies will need to reflect the differentiation of technologies and geographic resources, provide a stable policy environment to encourage investment, and incorporate mechanisms to respond to changing technological and market conditions.

Many aspects of renewable energy policies should be able to facilitate CDR development. RPSs can provide an overall structure that will assure installations

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continue at a steady pace. They also incentivize acquisition of the lowest-cost technologies, which will help contain overall costs and encourage continued innovation. FITs provide long-term subsidies that assure profitability, thereby encouraging investment into new technologies. Secondary policies, such as tax credits and cash grants, should be included because of their recognized effect of enhancing the effectiveness of primary policies. As the technologies mature, their costs will decline, thus causing a rush to install reduced-cost technologies at price-supported rates. Not only must the supporting policies be adjusted to contain their overall costs, governments should also transition to different policies that better reflect the new market realities. Thus, as technologies mature, FITs should be phased out in favor of policies, such as auctions, that can reduce installation prices.

TABLE OF CONTENTS

I. DEVELOPMENT OF CDR IS CRUCIAL BUT OCCURRING TOO SLOWLY

Because we have failed to rein in greenhouse gas emissions, planetary warming is likely to exceed either the 1.5°C target required to avoid significant climate changes or even the Paris Agreement's 2°C target. Most analyses conclude that to stay below these levels, we will need to deploy carbon dioxide removal technologies. Unfortunately, these technologies are largely undeveloped and few have been installed. Consequently, the number of installations will need to increase dramatically to sequester carbon at the rate required.

A. Surpassing Carbon Emissions Targets

Despite recent efforts to reduce carbon dioxide emissions, scientists still project that we will not avoid dangerous climate change. Models that calculate that we can avoid this result almost exclusively rely upon carbon dioxide removal options to stay below this level of warming. Although a number of CDR technologies are theoretically possible, they all have limitations. More germane here, they all remain far from the level of development and installation required.

The parties to the 2015 Paris Agreement agreed to aim to hold the rise in warming to "well below 2.0°C."[1] They further agreed to pursue efforts to hold

[1] Adoption of the Paris Agreement, UNFCC Conference of the Parties, 21st Sess., U.N. Doc. FCCC/CP/2015/10/Add.1 (Dec. 12, 2015), at art. 2(1)(a) (Paris Agreement) http://unfccc.int/files/home/application/pdf/paris_agreement.pdf.

warming to 1.5°C.[2] Recent analyses indicate that even warming to the 1.5°C level will cause serious regional consequences, such as extreme temperature warming, heavy precipitation, and droughts.[3] The Paris Agreements and earlier global pacts targeted a rise of 2.0°C as the level to avoid because at that level "dangerous anthropogenic interference with the climate system" will be unavoidable.[4] Failure to hold warming to 1.5°C could result in additional global damages costing between $8 to $38 trillion by midcentury.[5]

Unfortunately, temperature rises of this magnitude are becoming increasingly likely. The Intergovernmental Panel on Climate Change (IPCC) concluded that we can emit only an additional 1,000 Gt of CO_2 between 2011 and 2100 while retaining a 66% chance of keeping warming under 2°C.[6] With annual emissions approximating 37.5 Gt of CO_2,[7] society already emitted one-fifth of this amount in just five years.[8] Thus, scientists have estimated that our emissions will ensure a 1.5°C temperature rise in no more than 20 years, and possibly much sooner.[9]

Consequently, integrated assessment models developed by the IPCC in its Fifth Assessment Report revealed that deployment of CDR technologies are likely a critical component for avoiding the 2°C level at the end of the century. The IPCC noted that 166 of 900 integrated assessment models yielded a 66% chance of warming not exceeding the 2°C level in 2100. 101 of these models required CDR to achieve this result.[10] In fact, they redly upon CDR ramping up rapidly before midcentury to meet this target.[11]

Although 2100 is still many decades away, efforts to develop, test, and deploy CDR – at scale – must commence shortly. The IPCC models indicate that keeping warming below 1.5°C will require large-scale deployment of CDR within

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[2] *Id*.

[3] Valérie Masson-Delmotte et al, GLOBAL WARMING OF 1.5°C 8 (2018).

[4] Lena R. Boysen et al., *The Limits to Global-Warming Mitigation by Terrestrial Carbon Removal*, 5 EARTH'S FUTURE, MAY 17, 2017, 463, 463-474.

[5] Masson-Delmotte et al, *supra* note 3 at 256.

[6] EUROPEAN ACADAMIES SCIENCE ADVISORY COMMITTEE (EASAC), *Negative Emission Technologies: What Role in Meeting in Paris Agreement Targets?*, 35 EASAC POL'Y REP. 1, 4 (2018)

[7] UN ENVIRONMENTAL PROGRAMME (UNEP), THE EMISSIONS GAP REPORT 2019 (*Emissions Gap Report 2019*) 3 (2019).

[8] EASAC, *supra* note 6 at 5.

[9] David Kramer, *Negative Carbon Dioxide Emissions*, PHYSICS TODAY 73, 1, 44, 45 (2020); doi: 10.1063/PT.3.4389.

[10] Christopher B. Field & Katharine J. Mach, *Rightsizing Carbon Dioxide Removal*, 356 SCIENCE, 706, 707 (May 19, 2017).

[11] National Academies of Sciences, Engineering, and Medicine (NAS), NEGATIVE EMISSIONS TECHNOLOGIES AND RELIABLE SEQUESTRATION: A RESEARCH AGENDA 9 (2019).

10 to 20 years.[12] Even some projections to hold warming to 2.0°C will necessitate CDR deployment to begin as soon as the current decade.[13]

B. The State of CDR Technologies

Carbon dioxide removal consists of a range of practices and technologies that can reduce the amount of carbon dioxide in the atmosphere. Costs and physical limitations, however, are likely to prevent any single technology from providing a "magic bullet" solution. Consequently, we will need to develop and deploy a portfolio of technologies.

CDR technologies remove CO_2 from the atmosphere and sequester it underground permanently.[14] These technologies fall into two categories. The first involves methods that augment natural processes.[15] The second utilizes technological means to capture and bury the carbon dioxide.[16]

Although research on carbon dioxide removal is ongoing, the most promising approaches fall within the following eight categories:[17]

- *Afforestation and reforestation* – afforestation involves the planting of forests on grasslands or shrublands, and reforestation occurs when forests are planted on lands converted from forests to other purposes.[18] The amount of CO_2 removed from the atmosphere by forestation depends upon a number of factors, including the availability of sufficient land, nutrients,[19] and

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[12] R. Stuart Haszeldine et al., *Negative Emissions Technologies and Carbon Capture and Storage to Achieve the Paris Agreement Commitments*, 376 PHIL. TRANS. R. SOC. A 19-20 (Oct. 28, 2018).

[13] Matthew D. Eisaman, *Indirect Ocean Capture of Atmospheric CO_2: Part II. Understanding the Cost of Negative Emissions*, 1 INTERNATIONAL JOURNAL OF GREENHOUSE GAS CONTROL (2018).

[14] NATIONAL RESEARCH COUNCIL (NRC), CLIMATE INTERVENTION: CARBON DIOXIDE REMOVAL AND RELIABLE SEQUESTRATION 33 (2015). Carbon capture and utilization systems, on the other hand, apply the captured CO_2 to a number of processes, including enhanced oil recovery, mineral carbonation, food and beverage carbonation, polymer processing, microalgae production, and enhanced coal bed methane recovery. Jennifer Wilcox, Peter C Psarras & Simona Liguori, Assessment of Reasonable Opportunities for Direct Air Capture, 12 ENVT'L. RES. LETTERS 1, 2 (2017).

[15] *Id*.

[16] *Id*.

[17] Another approach gaining attention recently is Coastal Blue Carbon. This consists of tidal wetlands and seagrasses, which capture and sequester carbon through plant growth and the subsequent burial of this plant organic carbon residue. NAS, *supra* note 11 at 45. While these areas are among the most robust on earth at sequestering carbon, their current global sequestration totals only 0.84 $GtCO_2$ per year. *Id*. at 46. However, scientists have projected that this rate could more than double through the restoration and creation of coastal wetlands. *Id*. at 47.

[18] *Id*. at 39. These processes are necessitated by deforestation, which causes approximately 10% of anthropogenic greenhouse gas emissions. NRC, *supra* note 14 at 39.

[19] EASAC, *supra* note 6 at 17.

water;[20] type and age of the trees;[21] and precipitation and CO_2 levels.[22] Possible sequestration from these activities could range from 1.5 to 14 $GtCO_2$ (billion tons of carbon dioxide) per year by 2030.[23]

- *Biochar* – pyrolysis stabilizes biomass in biochar, which is then buried in soil.[24] Biochar constitutes a negative emissions technology because it fixes atmospheric CO_2 in a stable form that can be easily sequestered.[25] Additionally, biochar can provide several co-benefits. These include increasing soil fertility and improving water and nutrient retention.[26] Scientists project that biochar can sequester as much as 1 $GtCO_2$ per year by 2030, and possibly up to 9.5 $GtCO_2$, by 2100.[27]

- *Bioenergy carbon capture and sequestration* (*BECCS*) – combining carbon capture and sequestration technology with the burning of biomass in the form of agricultural and forest residues, municipal wastes, and cultivated crops in power plants can have net negative CO_2 emissions.[28] Since biomass burning is in theory carbon neutral, and in practice low carbon, the capture and sequestration of the system's emissions results in net negative emissions.[29] A critical advantage of BECCS as a carbon dioxide removal technology is that it also produces a salable product, electricity.[30] BECCS could sequester between 2 and 18 $GtCO_2$ per year.[31]

- *Direct air capture and carbon sequestration* (*DACCS*) – this involves directly capturing ambient air, separating the CO_2, and then sequestering it underground.[32] DACCS technology is still at the developmental stage. While it may eventually provide up to half of the required CO_2 storage, it will necessitate significant energy and land resources to operate at this

[20] Duncan McLaren, *Negatonnes—An Initial Assessment of the Potential For Negative Emission Techniques to Contribute Safely and Fairly to Meeting Carbon Budgets in the 21st Century*, 1 FRIENDS OF THE EARTH 1, 20 (2011).

[21] In general, net CO_2 removal peaks within 30-40 years, and then it declines to zero as the forest matures. NRC, *supra* note 14 at 40.

[22] *Id*.

[23] *Id*.

[24] UN ENVIRONMETAL PROGRAMME (UNEP), THE EMISSIONS GAP REPORT 2017: A UN ENVIRONMENT SYNTHESIS REPORT (*Emissions Gap Report 2017*) 62 (2017).

[25] Niall McGlashan et al., *High-Level Techno-Economic Assessment of Negative Emissions Technologies*, 90 PROCESS SAFETY & ENVT'L. PROTECTION 501-10, 503 (2012).

[26] UNEP, *Emissions Gap Report 2017*, *supra* note 24 at 62.

[27] McGlashan, *supra* note 25 at 503.

[28] Matthew C. Nisbet, THE CARBON REMOVAL DEBATE 9 (2019).

[29] McLaren, *supra* note 20 at 17.

[30] McGlashan, *supra* note 25 at 504.

[31] UNEP, *Emissions Gap Report 2017*, *supra* note 24 at 62. *See also* Elmar Kriegler et al., *Is Atmospheric Carbon Dioxide Removal a Gamer Changer for Climate Change Mitigation?*, 118 CLIMATIC CHANGE 45-57, 55 (May, 2013) (projecting BECCS deployment limited to a removal of 14-15 $GtCO_2$ per year).

[32] NAS, *supra* note 11 at 39.

scale.[33] DACCS has the technical potential to sequester as much as 20 $GtCO_2$ annually, but actual sequestration is most likely to range from 2 to 5 $GtCO_2$ per year.[34]

- *Enhanced weathering* – atmospheric CO_2 naturally forms a chemical bond with reactive minerals.[35] The natural weathering process will remove atmospheric carbon, but it will require 100,000 years to return the climate to its preindustrial level.[36] Accelerated weathering augments the natural weathering process. It involves mining and grinding particular minerals to small grain sizes to increase their surface area exposed for weathering.[37] This method likely can sequester only 0.7 to 3.7 $GtCO_2$ per year.[38]

- *Land management* – soils lose carbon through oxidation, such as when they are plowed.[39] In fact, agricultural practices are responsible for 10-12% of anthropogenic greenhouse gases.[40] Appropriate land management practices can increase soil carbon capture and reduce soil carbon losses.[41] These practices include accelerating regeneration after disturbance and lengthening crop rotations.[42] Possible sequestration from agricultural land management practices may be as high as 5.2 $GtCO_2$ per year.[43]

- *Ocean alkalinity enhancement* – adding alkaline materials to the ocean increases the amount of carbon the ocean absorbs.[44] Ocean alkalinity enhancement accelerates ocean carbon uptake and at the same time reverses ocean acidification.[45] If operated at the appropriate scale, this method could sequester sufficient carbon to return the atmosphere to its pre-industrial state.[46]

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[33] Kramer, *supra* note 9 at 49.
[34] *Id*. at 64.
[35] NAS, *supra* note 11 at 39.
[36] Jeremy Deaton, *Earth's "Weathering Thermostat" Keeps Climate in Check Over Very Long Periods of Time*, CLEANTECHNICA (Sept. 18, 2017), https://cleantechnica.com/2017/09/18/earths-weathering-thermostat-keeps-climate-check-long-periods-time/.
[37] Jessica Strefler et al., *Potential and Costs of Carbon Dioxide Removal by Enhanced Weathering of Rocks*, 13 ENV'T. RES. LETTERS 1, 1-2 (2018).
[38] UNEP, *Emissions Gap Report 2017*, *supra* note 24 at 64.
[39] McLaren, *supra* note 20 at 21.
[40] Stefan Frank et al., *Reducing Greenhouse Gas Emissions in Agriculture Without Compromising Food Security?*, 12 ENVT'L. RES. LETTERS 1, 2 (2017).
[41] UNEP, *Emissions Gap Report 2017*, *supra* note 24 at 61.
[42] NAS, *supra* note 11 at 39.
[43] NRC, *supra* note 14 at 44.
[44] *Id*.
[45] Andrew Lenton, *Assessing Carbon Dioxide Removal through Global and Regional Ocean Alkalinization under High and Low Emission Pathways*, 9 EARTH SYS. DYNAMICS 339-357, 340 (2018).
[46] T. Kruger, *Increasing the Alkalinity of the Ocean to Enhance its Capacity to Act as a Carbon Sink and to Counteract the Effect of Ocean Acidification*, in GeoConvention, 4 (2010), http://www.searchanddiscovery.com/abstracts/pdf/2014/90172cspg/abstracts/ndx_krug.pdf

- *Ocean fertilization* – depositing nutrients, such as iron, nitrogen or phosphorous, into the ocean stimulates the growth of phytoplankton, which consume CO_2.[47] Scientists project that ocean fertilization could remove up to 3.7 $GtCO_2$ per year.[48]

Several considerations regarding these technologies are important. First, we cannot rely upon developing a single technology; instead, will need to develop a portfolio of technologies.[49] Second, physical constraints limit the actual amount of CO_2 that every method can sequester.[50] Third, "significant scientific gaps" exist for nearly all CDR technologies.[51] Fourth, few CDR methods, if any, are ready to be deployed at the scale required.[52]

Thus, we can anticipate that we will need to utilize CDR technologies, yet they are both substantially underdeveloped and not fully understood. We need to institute policies that will encourage CDR's development and deployment.

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47 EASAC, *supra* note 6 at 27.

48 NRC, *supra* note 14 at 61.

49 This is apparent for several reasons. First, current global CO_2 emissions approximate 37.5 $GtCO_2$ per year. UNEP, *Emissions Gap Report 2019*, *supra* note 7 at 3. As indicated above, no single technology, except possibly ocean alkalinization, will be able to keep pace with these annual emissions, let alone actually reduce the amount of atmospheric CO_2. Furthermore, a broad portfolio of technologies will be less expensive and less disruptive; diversification will also help manage the risks of untested technologies. NAS, *supra* note 11 at 4.

50 *See Id*. at 10-11 for several such limitations. In addition, several CDR approaches may compete with one another. BECCS, afforestation, reforestation, DACCS, and enhanced weathering all may draw upon the same land and water resources. EASAC, *supra* note 6 at 12-13. Moreover, methods that rely upon reactions with minerals – such as weathering and alkalinization – may confront limitations deriving from the quantity of minerals that must be extracted, processed, and transported. McLaren, *supra* note 20 at 17.

51 NAS, *supra* note 11 at 13. Many CDR technologies are little more than concepts and operate only as pilot projects. Haszeldine, et al, *supra* note 12 at 11. Some have not yet even been tried in the field. NAS, *supra* note 11 at 7.

52 BECCS, for example, is considered among the most promising of the CDR technologies. Vassilis Stavrakas, Niki-Artemis Spyridaki & Alexandros Flamos, *Striving towards the Deployment of Bio-Energy with Carbon Capture and Storage (BECCS): A Review of Research Priorities and Assessment Needs*, SUSTAINABILITY 2 (2018). Current BECCS operations, however, consist of only fifteen pilot plants and one commercial plant. Wil Burns & Simon Nicholson, *Bioenergy and Carbon Capture with Storage (BECCS): the Prospects and Challenges of an Emerging Climate Policy* Response, 7 J. ENVT'L. STUD. & SCI. 527, 529 (2017). Nevertheless, the IPCC scenarios that rely on BECCS to keep warming under 2.0°C require that BECCS plants be deployed in the tens of thousands over the next few decades. Nisbet, *supra* note 28 at 7. Similarly, these scenarios anticipate that several thousand DACCS plants will be operating by 2030; planned construction, however, only numbers in the tens. Glen P. Peters et al., *Key Indicators to Track Current Progress and Future Ambition of the Paris Agreement*, 121 NATURE CLIMATE CHANGE 1, 4 (2017). Finally, deploying biochar at the necessary scale would require an increase of over 63 times the current charcoal production capacity. Niall R. McGlashan et al., Negative Emissions Technologies, 8 Grantham Institute for Climate Change Briefing Paper, October, 2012, at 15.

II. DIFFUSION OF NEW TECHNOLOGIES

To best encourage the development and deployment of CDR technologies, we need to consider the historic patterns of technology diffusion. The distribution of new technologies typically follows a recurring pattern. These patterns proceed on a path reflecting the technologies' initial uncertainty, acceleration of their adoption as they become technologically mature, and then saturation of the market. Researchers have recognized a number of factors that drive these patterns. Examining these patterns informs expectations for future technology dissemination, the choice of policies to accelerate their distribution, means to augment their diffusion, and inflection points where policies may need to change.

Technology "diffusion" identifies the process by which "an innovation is communicated through certain channels over time among members of a social system."[53] Diffusion modeling informs the understanding of the growth of technologies.[54] It illustrates that the market share of new technologies does not grow linearly; instead, it typically follows an "S" shape.[55]

Gabriel Tarde first developed diffusion theory in 1903, recognizing the S shape that it follows.[56] Subsequently, scientists have applied diffusion models to analyze the adoption of numerous technologies, including cars, televisions, computers, other consumer goods, and non-commercial phenomena.[57] Applying diffusion-models analysis helps design and assess supporting policies.[58] For instance, as this analysis demonstrates, new technologies typically require initial supporting policies before achieving diffusion and maturity, and maintaining these policies during later stages may be counterproductive.[59]

In the 1950's and 1960's, economists became more engaged in diffusion analysis. They especially focused on understanding the patterns of diffusion.[60] The general pattern of technology diffusion consists of a slow start, acceration to a peak,

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[53] G. Joga Rao, S.K Shrivastava, & Gouse Baig, *Diffusion Modeling and Implementation of Renewable Energy Technologies in India*, INTERNATIONAL ADVANCED RESEARCH JOURNAL IN SCIENCE, ENGINEERING AND TECHNOLOGY, Vol. 3, Issue 8, 106-119, 110 (August 2016).

[54] K. Usha Rao & V.V.N. Kishore, *A Review of Technology Diffusion Models with Special Reference to Renewable Energy Technologies*, RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 14 (2010) 1070–1078, 1075.

[55] Stephen W. Davies & Ivan Diaz-Rainey, *The Patterns of Induced Diffusion: Evidence from the International Diffusion of Wind Energy*, TECHNOLOGICAL FORECASTING & SOCIAL CHANGE 78 (2011) 1227–1241, 1229.

[56] Cinderella Dube & Victor Gumbo, *Diffusion of Innovation and the Technology Adoption Curve: Where Are We? The Zimbabwean Experience*, BUSINESS AND MANAGEMENT STUDIES Vol. 3, No. 3 (September 2017) 34-52, 36. Technology diffusion derives from the recognition of growth patterns of cell colonies in a medium. Colony growth reaches a saturation point because of nutrient or space limitations. Similarly, technology diffusion levels off as it approaches the number of potential adopters. Rao, Shrivastava, & Baig, *supra* note 53 at 110.

[57] *Id*. These non-commercial phenomena includes things such as fatal car accidents, major nuclear accidents, and deaths from AIDS. *Id*.

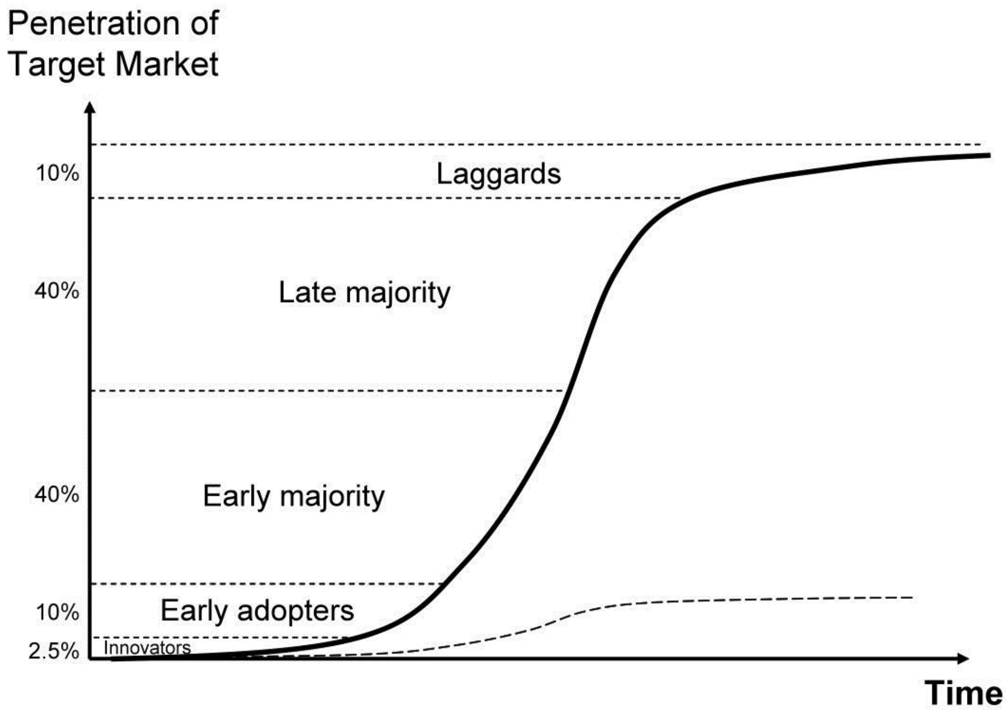
[58] Rao & Kishore, *supra* note 54 at 1075.

[59] Stéphane Isoard & Antonio Soria, *Technical Change Dynamics: Evidence from the Emerging Renewable Energy Technologies*, ENERGY ECONOMICS 23 (2001) 619-636, 631.

[60] Davies & Diaz-Rainey, *supra* note 55 at 1228.

and then a slowing as saturation occurs.[61] Analysts refer to this pattern as the S curve, as reflected below:

Figure 1[62]



The S curve begins with a relatively flat inception stage. During this stage, the technology first appears in commercial markets. Costs, however, remain relatively high, suppressing purchases.[63] Next, in the take-off phase, the market for the technology expands quickly, and costs begin to fall.[64] In the final stage, consolidation,[65] growth flattens as the market approaches saturation.[66] Development of renewable energy followed the S-curve pattern, as evidenced by its rate of adoption. Production of the first trillion watts of renewable energy required 40 years; the second trillion needed only 5 years.[67]

As technologies progress through these stages, different barriers to deployment arise, often necessitating adjustments to supporting policies.[68] During the inception phase, developers focus on establishing the costs and potential of technologies. Typically, this involves the construction of pilot or demonstration

[61] International Energy Agency (IEA), DEPLOYING RENEWABLES 2011 (*Deploying Renewables*) 97 (2011).
[62] InvestAura, *The Adoption Curve*, last visited August 15, 2019, available at http://www.business-planning-for-managers.com/main-courses/marketing-sales/marketing/the-adoption-curve/.
[63] IEA, *Deploying Renewables*, *supra* note 61 at 97.
[64] *Id*.
[65] *Id*.
[66] Rao, Shrivastava, & Baig, *supra* note 53 at 110.
[67] Jeremy Hodges, *Global Green Energy Capacity Surpasses a Trillion Watts*, BLOOMBERG LAW ENVIRONMENT & ENERGY REPORT (August 2, 2018).
[68] IEA, *Deploying Renewables*, *supra* note 61 at 97.

plants, developing the requisite administrative (permitting) infrastructure, and establishing the necessary supply chains.[69] Policy considerations in the inception phase include policies that set the groundwork for long-term favorable conditions and that compensate for the high costs at this stage.[70]

The take-off phase presents different challenges. During this stage, the infrastructure investments of the inception phase facilitate fast growth of installed capacity until markets approach saturation.[71] At this stage, policies must be stable yet flexible. Stability is necessary to maintain investor confidence;[72] flexibility is required because support costs can rise dramatically as deployments take off.[73] Either flexible policies or those that are transitional in nature best respond to issues arising at this stage.[74] Accordingly, at this stage incentives must decrease over time to prevent policy costs from skyrocketing.[75]

Finally, in the saturation or consolidation stage, the issues are much simpler. At this stage, most of the market has already adopted the technology, and the remaining market consists of last adopters, identified as "laggards."[76] Thus, the issues largely consist of dissemination to these remaining adopters and integration of the technologies at substantial levels of adoption.[77]

Over time, economists have refined their analysis of diffusion patterns, focusing on inducing diffusion, accelerating diffusion, and identifying diffusion pivot points. Induced diffusion involves interventions that alter the speed or total level of diffusion of an innovation.[78] Although physical limitations can cap diffusion levels, government policies targeting specific technologies can accelerate diffusion.[79] Induced diffusion can result from policies that facilitate adoption or sustain the adoption process.[80] Graphically, the changes to the typical S curve engendered by induced diffusion involve a shifting of the curve to the left (accelerated diffusion) or a higher end point (increased saturation).[81] Absent

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[69] *Id*. at 101.
[70] *Id*. A particular concern at this stage is the technological "valley of death," during which technologies requiring large scale demonstration lack the requisite financing. These risks especially arise for large-scale projects that require substantial funding to develop and construct demonstration models. *Id*. at 101-02.
[71] *Id*. at 110.
[72] *Id*. at 103. The most successful systems have had such policy continuity. Davies & Diaz-Rainey, *supra* note 55 at 1236.
[73] IEA, *Deploying Renewables*, *supra* note 61 at 102.
[74] *Id*. at 103.
[75] *Id*.
[76] Rao, Shrivastava, & Baig, *supra* note 53 at 110.
[77] IEA, *Deploying Renewables*, *supra* note 61 at 104.
[78] Sergio Giaccaria & Silvana Dalmazzone, *Patterns of Induced Diffusion of Renewable Energy Capacity: The Role of Regulatory Design and Decentralization*, No. 282 CARLO ALBERTO NOTEBOOKS 2 (2012).
[79] C. Nolden, *The Governance of Innovation Diffusion – A Socio-Technical Analysis of Energy Policy*, EPJ Web of Conferences 33 (2012) at 2-3.
[80] Giaccaria & Dalmazzone, *supra* note 78 at 2.
[81] Ivan Diaz-Rainey, *Induced Diffusion: Definition, Review and Suggestions for Further Research*, SSRN ELECTRONIC JOURNAL 6-7 (2009).

sufficient policy interventions, diffusion will follow the typical pattern. Strong policy inducements, however, can favorably reshape the diffusion curve.[82]

The success of induced diffusion can depend upon a number of considerations, including supporting policies.[83] Prime examples of the interaction of policy and diffusion come from the development of renewable energy. Many European countries successfully induced the diffusion of wind power.[84] During its inception, these countries provided financial incentives for demonstration wind projects.[85] The most successful European nations in inducing wind power's diffusion enacted feed-in tariffs (FITs).[86] Characteristics of FITs that facilitated diffusion included revenue certainty, policy continuity, and removal of non-price (primarily grid access) barriers.[87] Support measures such as FITs helped renewable energy costs to decline, creating new demand. This triggered learning by doing[88] and economies of scale,[89] which pushed costs down further.[90]

Research into diffusion of renewable energy has identified several factors that facilitate cost reductions. These included experience with the technology, as exhibited through a learning curve analysis, and economies of scale.[91] Technologies proceed down the learning curve in a recurring pattern. Research and development facilitate initial cost declines; then, performance standards dominate, and price reductions drive demand.[92] As developers gain more experience with new technologies, they are able to increase productivity through R&D, experimentation, and implementation.[93] This reduces time and labor costs, lowering unit costs of production.[94]

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82 Davies & Diaz-Rainey, *supra* note 55 at 1237.
83 *Id*. at 1229.
84 *Id*. at 1235.
85 Rao & Kishore, *supra* note 54 at 1072-73.
86 Davies & Diaz-Rainey, *supra* note 55 at 1236.
87 *Id*. FITs are discussed more fully *infra* at Section III.A.
88 "Learning by doing" refers to a concept in economics that costs decline as production increases because manufacturers learn how to produce the technology more efficiently. Saed Alizamir, Francis de Véricourt, & Peng Sun (2016) *Efficient Feed-In-Tariff Policies for Renewable,* OPERATIONS RESEARCH 64 (1): 52-66, 53. In addition, labor becomes more skilled at production. Björn A. Sandén & Christian Azar, *Near-term Technology Policies for Long-Term Climate Targets – Economy Wide Versus Technology Specific Approaches*, ENERGY POLICY (2005) 1557–1576, 1559.These improvements also can generate positive feedbacks, which further benefit product development. *Id*.
89 "Economies of scale" occur as production costs per unit of output fall as fixed costs get spread over an increasing volume of production. Rising production volumes also enable efficiencies through greater divisions of labor. *Id*.
90 Malcolm Keay & David Robinson, THE LIMITS OF AUCTIONS: REFLECTIONS ON THE ROLE OF CENTRAL PURCHASER AUCTIONS FOR LONG-TERM COMMITMENTS IN ELECTRICITY SYSTEMS 4 (2019). One analyst concludes that for each doubling of installed capacity, prices fall by 7% because of economies of scale and supply chain efficiencies. Nolden, *supra* note 79 at 5-6.
91 Rao, Shrivastava, & Baig, *supra* note 53 at 115.
92 David Roberts, *What Made Solar Panels So Cheap? Thank Government Policy*., VOX (December 28, 2018), available at https://www.vox.com/energy-and-environment/2018/11/20/18104206/solar-panels-cost-cheap-mit-clean-energy-policy.
93 Rao & Kishore, *supra* note 54 at 1073.
94 Isoard & Soria, *supra* note 59 at 621.

Awareness of the S-curve pattern informs policy development for technology incentivization and diffusion. Specifically, it indicates that the growth of technologies will usually follow a nonlinear pattern. Consequently, slow initial growth is foreseeable and should not, by itself, trigger policy changes.[95] Policy stability enhances effectiveness. In fact, policy stability is a more important determinant of diffusion than financial support.[96] Conversely, regular changes to policies limit their effectiveness.[97]

Renewable energy diffusion exhibited many of these characteristics. Government policies facilitated its development to the point where costs dropped as a result of learning and mass production.[98] Renewables then proceeded along a path of research and development, demonstration models, market introduction, and diffusion.[99] Economists have estimated that research and development, economies of scale, and learning-by-doing accounted for 60 percent of the cost decline of solar photovoltaic panels from 1980 to 2012.[100] Over a slightly longer period (1975 to 2015), the cost of PVs dropped 99 percent.[101] As the technology improved, economies of scale became the dominant source of cost reductions.[102]

The government policies that facilitated renewable energy diffusion included supply-side and demand-side approaches. Supply side policies facilitate delivering new technologies to markets.[103] Price subsidies are classic examples of such policies, and they can play critical roles in facilitating diffusion.[104] Among such subsides, FITs especially have been successful in promoting diffusion by encouraging learning and reducing costs.[105] Demand-side policies directly target consumption of the technology. For instance, renewable portfolio standards (RPSs) in the United States are exemplars of these approaches.[106] RPSs mandate that electricity providers receive a particular portion of their electricity from renewable sources, thus necessitating the installation of those resources.[107] Alternatively, tax

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95 Davis & Diaz-Rainey, *supra* note 55 at 1235.
96 Inga Boie, DETERMINANTS FOR THE MARKET DIFFUSION OF RENEWABLE ENERGY TECHNOLOGIES 242-43 (2016).
97 Rao & Kishore, *supra* note 54 at 1074. One example of the impact of policy uncertainty comes from the recurring expirations and extensions of the wind production tax credit in the United States, discussed more fully *infra* at III.E.
98 *Id*. at 1073.
99 Rao, Shrivastava, & Baig, *supra* note 53 at 114. As technologies progress through these stages, supporting policies should be flexible; costs will usually have fallen sufficiently to render subsidies unnecessary. Nolden, *supra* note 79 at 3.
100 Goksin Kavlak, James McNerney, & Jessika E. Trancik, *Evaluating the Causes of Cost Reduction in Photovoltaic Modules*, ENERGY POLICY 123 (2018) 700–710, 709.
101 Roberts, *supra* note 92.
102 Kavlak, McNerney, & Trancik, *supra* note 100 at 709.
103 Juliana Subtil Lacerda & Jeroen C. J. M. van den Bergh, *International Diffusion of Renewable Energy Innovations: Lessons from the Lead Markets for Wind Power in China, Germany and USA*, ENERGIES 2014, 7, 8236-8263, 8240.
104 Patrik Söderholm & Ger Klaassen, *Wind Power in Europe: A Simultaneous Innovation–Diffusion Model*, ENVIRONMENTAL & RESOURCE ECONOMICS (2007) 36:163–190, 183.
105 *Id*. Experts credit FITs with incentivizing a substantial majority of renewable energy installations. *See infra* n.130 and accompanying text.
106 Lacerda & van den Bergh, *supra* note 103 at 8251.
107 Corey N. Allen, *Untapped Renewable Energy Potential: Lessons for Reforming Virginia's*

credits, by reducing net installation costs, also stimulate demand.[108] Demand-side strategies, by stimulating demand for new technologies, generate production, which enhances learning-by-doing and economies of scale.[109] Increased production can then reinforce these effects by reducing costs, accelerating economies of scale, and inducing further learning effects.[110]

To achieve these results, governments used policies that created financial incentives or imposed quantity regulations to generate demand for renewable energy.[111] Government policies were critical to incentivizing private activity that drove down costs.[112] Figure 2 illustrates the relationship between cost and volume in the utility-scale solar power market. As solar power production and installation accelerated, production moved down the cost curve, thereby further reducing costs.[113] Experience demonstrates that costs of new technologies initially decline as the technology improves; then, costs fall in conjunction with increases in market volume.[114]

Renewable Energy Portfolio Standard from Texas and California, 35 VA. ENVTL. L.J. 117, 120 (2016). RPSs are discussed more fully *infra* at Section III.D.

[108] *See* discussion *infra* at Section III.E.

[109] Lacerda & van den Bergh, *supra* note 103 at 8242-43.

[110] Isoard & Soria, *supra* note 59 at 620.

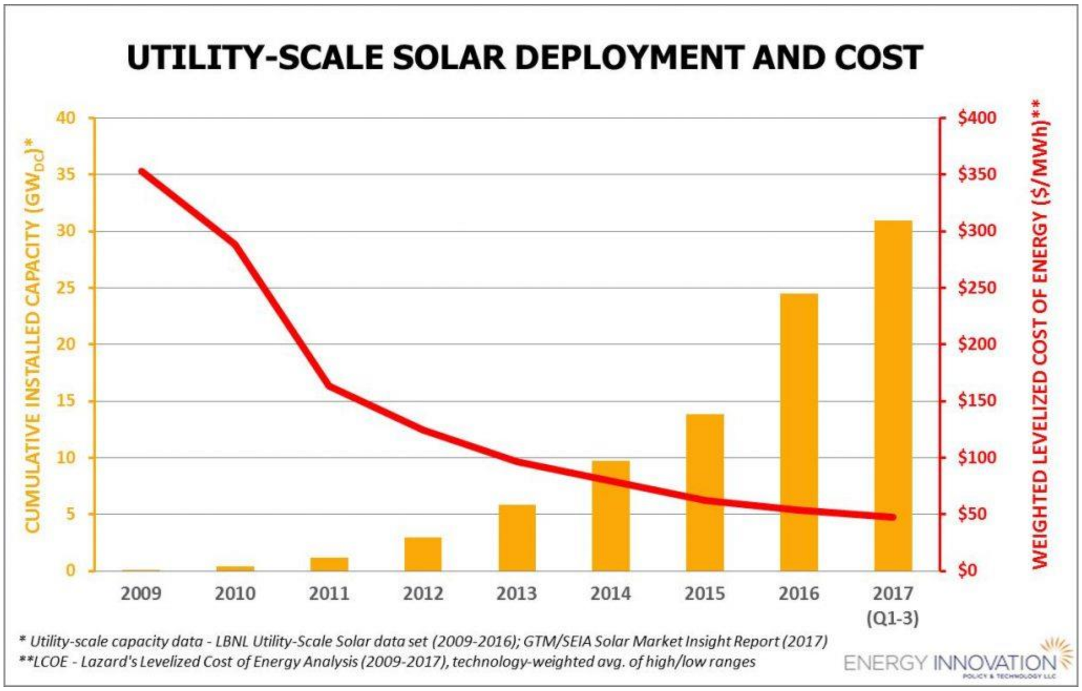
[111] Rao & Kishore, *supra* note 54 at 1075.

[112] *Id*. at 709.

[113] Isoard & Soria, *supra* note 59 at 623. The decline in PV costs and their resulting rapid increase in installations provide a recent example of this process. Kavlak, McNerney, & Trancik, *supra* note 100 at 700.

[114] Hans-Josef Fell, *The Shift From Feed-In-Tariffs to Tenders Is Hindering the Transformation of the Global Energy Supply to Renewable Energies* 15 (July 2017).

Figure 2[115]



Renewable energy markets actually contain many sub-markets, and diffusion occurred uniquely within each. Thus, different technologies developed at separate paces; consequently, each falls at unique locations on their individual technology curves.[116] Even individual technologies may fall at different stages of the curve in different geographic levels. Thus, local or national markets may be at one stage while the global technology curve may be at another.[117] Because of these differences, governments must be alert to tailor policies to local circumstances.[118] This also suggests that policy makers should develop technology-specific, rather

[115] Megan Mahajan, *Plunging Prices Mean Building New Renewable Energy Is Cheaper Than Running Existing Coal*, FORBES (December 3, 2018), available at https://www.forbes.com/sites/energyinnovation/2018/12/03/plunging-prices-mean-building-new-renewable-energy-is-cheaper-than-running-existing-coal/#1cd0aad831f3.

[116] IEA, *Deploying Renewables*, *supra* note 61 at 95.

[117] *Id*. at 97. Not surprisingly, progress made in early-adopter nations can benefit late adopter states. Typically, late adopters experience much faster growth rates, even if they have lower GDPs. Jorrit Gosens, Fredrik Hedenus, Björn A. Sandén, *Faster Market Growth of Wind and PV in Late Adopters Due to Global Experience Build-up*, ENERGY 131 (2017) 267-278, 275. Even when policies have limited effect in the initial markets, they may have a multiplier effect by accelerating growth in the markets of late-adopter nations. *Id*. One estimate calculated that late-adopter countries were able to build out wind power nearly five times faster than the initial countries; solar could grow as much as 16 times faster. *Id*. at 267.

[118] IEA, *Deploying Renewables*, *supra* note 61 at 100.

than technology-neutral, policies.[119] As a result, applying policies that allow for individualization of application to separate technologies is a critical consideration.

In conclusion, we can anticipate that the growth and diffusion of CDR technologies will likely follow a recurring pattern. Armed with this knowledge, governments can more accurately tailor policies to enhance their ability to increase technological diffusion while containing their costs. The experience of renewable energy diffusion, discussed next, illustrates how policies can support diffusion, but also demonstrates some of the problems that may arise if not done correctly.

III. POLICIES SUPPORTING RENEWABLE ENERGY DIFFUSION

The development of renewable energy exhibited the S-curve pattern. This diffusion occurred in significant part because of a number of policies that facilitated investment in these technologies. This next section will examine these policies more closely and their effects on renewable energy deployment.

A. Feed-In Tariffs – The Basics

Without doubt, feed-in tariffs (FITs) have been the most successful policy for incentivizing the investment in and diffusion of renewable energy. This is largely because they provide investors with certainty – a guaranteed, profitable return on their investments. Unfortunately, this source of their success has also caused many countries recently to abandon these policies at the peak of their success. In other words, as technologies reached the take-off stage, policies that were appropriate in the initial phase needed to be modified under the new circumstances. This suggests that awareness of diffusion patterns can guide policy makers to tailor their policies to maximize their effectiveness and to control their costs.

Germany and Spain first instituted elements of what were to become their FITs in the 1970's and 1980's.[120] Subsequently, Germany enacted its FIT in 1991,[121] and Spain followed in 1994.[122] Since then, FITs have become widely adopted. They have been and remain the most prominent form of policy adopted to support renewable energy production.[123] 65 nations,[124] and 110 jurisdictions

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[119] *Id*.

[120] In 1979, Germany passed a national competition law, which mandated purchases of renewable energy at avoided costs. Lincoln L. Davies & Kirsten Allen, *Feed-in Tariffs in Turmoil*, 116 W. VA. L. REV. 937, 946 (2014). Spain's Law 82/1980 required network connection and guaranteed contract prices. *Id*. at 968.

[121] Yugo Tanaka, *Feed-in Tariff Pricing and Social Burden in Japan: Evaluating International Learning through a Policy Transfer*, SOC. SCI. 2017, 6, 127 at 2.

[122] Davies & Allen, *supra* note 120 at 969.

[123] REN21, RENEWABLES 2017 GLOBAL STATUS REPORT 122 (2017).

[124] UN ENVIRONMENTAL PROGRAMME (UNEP), FEED-IN TARIFFS AS A POLICY INSTRUMENT FOR PROMOTING RENEWABLE ENERGIES AND GREEN ECONOMIES IN DEVELOPING COUNTRIES (*Feed-in Tariffs*) 4 (2012).

overall, use FITs.[125] FITs have played particularly significant roles in Europe, and most countries in Asia use them, as well.[126]

FITs have been quite successful, too. Most studies have concluded that FITs significantly stimulated the growth of renewable energy, especially in nations at the initial stages of technology development.[127] Often their performance has exceeded projections.[128] Researchers consider FITs to be the primary cause of renewable energy growth in their founding states of Germany and Spain.[129] Overall, analysts attribute 64% of global wind and 87% of solar photovoltaic (PV) installations to the use of FITs policies.[130]

Feed-in tariff agreements include particular components.[131] The "feed-in" provision assures that generators of electricity from renewable sources will have access to the grid.[132] The "tariff" requires utilities to purchase the electricity generated by designated sources at predetermined rates.[133] Finally, FITs contracts are usually required to last an extended period of time, typically at least 15-20 years.[134]

Feed-in tariffs essentially guarantee payments at above-cost rates to electricity producers through long-term contracts.[135] FITs are production-based incentives, as distinct from incentives awarded for installation. Thus, FITs provide their benefits not when a renewable energy facility is built, but when it actually generates electricity.[136] The theoretical basis supporting FITs is that assuring payment at a guaranteed price removes market risk from investors. This helps to

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[125] REN21, *supra* note 123 at 21.
[126] Chris Lo, *Renewable Energy: Are Feed-In Tariffs Going out of Style?*, POWER TECHNOLGY (January 18 2017), available at https://www.power-technology.com/features/featurerenewable-energy-are-feed-in-tariffs-going-out-of-style-5718419/. The United States has some utility-based FITs and state-wide FITs. Karlynn Cory, Toby Couture, & Claire Kreycik, FEED-IN TARIFF POLICY: DESIGN, IMPLEMENTATION, AND RPS POLICY INTERACTIONS 9 (2009).
[127] Hojin Kang, ESTABLISHING A NEW GUIDELINE FOR SOUTH KOREA'S RENEWABLE PORTFOLIO STANDARD 71 (2016).
[128] Tanaka, *supra* note 121 at 5.
[129] Cory, Couture, & Kreycik, *supra* note 126 at 1.
[130] UNEP, *Feed-in Tariffs*, *supra* note 124 at 5.
[131] Leah C. Stokes, *The Politics of Renewable Energy Policies: The Case of Feed-In Tariffs in Ontario, Canada*, ENERGY POLICY 56 (2013) 490-500, 490.
[132] Felix Mormann, *Clean Energy Federalism* (*Clean Energy Federalism*), 67 FLA. L. REV. 1621, 1631-32 (2016). The tariff functions similarly to a "must take" clause in a power purchase agreement. UNEP, *Feed-in Tariffs*, *supra* note 124 at 57. In a power purchase agreement, a third-party developer owns and operates a renewable energy system, and a customer contracts to purchase the output of this system. Environmental Protection Agency, *Solar Power Purchase Agreements*, last visited August 8, 2019, available at https://www.epa.gov/greenpower/solar-power-purchase-agreements. The agreement then requires the customer to purchase the electricity generated by the operator. Stoel Rives, LLP, THE LAW OF SOLAR: A GUIDE TO BUSINESS AND LEGAL ISSUES, Chapter 3, page 2 (2017).
[133] Mormann, *Clean Energy Federalism*, *supra* note 132 at 1631-32.
[134] IEA, *supra* note 61 at 79-80.
[135] *Id*. at 79.
[136] Toby Couture & Karlynn Cory, STATE CLEAN ENERGY POLICIES ANALYSIS (SCEPA) PROJECT: AN ANALYSIS OF RENEWABLE ENERGY FEED-IN TARIFFS IN THE UNITED STATES 2 (2009).

attract capital.[137] Indeed, the experience with FITs in Europe provides evidence that they succeeded.[138]

The 15-20 year length of FITs contracts plays an important role. Sometimes referred to as payment length or payment duration, this assures that generators will receive the FIT above-cost premium for an extended period.[139] This guaranteed duration is a key component in providing a financial incentive to invest in a qualifying project.[140]

Lengthy contracts provide other benefits, as well. With a longer contract, the period over which costs will be recovered increases. This reduces the levelized cost for the project.[141] One analysis concluded that the reduced capital costs can lower the levelized costs by 10-30%.[142] Long contracts assure stable revenue streams, which also minimize investor risk.[143] Lengthy contracts, as well as policy stability generally, provide assurance to the finance sector, too, which facilitates financing.[144] The length and stability of FITs also encourages secondary industries, such as equipment supply, to make the necessary investments essential to assure the long-term prospects of the primary industry.[145] Besides long contracts, feed-in tariff legislation often requires standardized contracts. Their use simplifies project development since it reduces or eliminates the negotiation process.[146]

The reimbursement rate set under FITs is critical.[147] Policy makers select from three different means to calculate the rate: actual cost, avoided cost or value, or market price plus premium. A cost-based price starts with the cost of electricity generation from the renewable source and adds an amount to provide a guaranteed return.[148] As such, this rate is independent of the market price.[149] Cost-based rates are most likely to assure developers and investors with their guaranteed returns. Consequently, this method is particularly effective in promoting market growth.[150] Since the cost-based system derives from the cost to generate electricity, the method

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[137] Richard Schmalensee, *Evaluating Policies to Increase Electricity Generation from Renewable Energy*, REVIEW OF ENVIRONMENTAL ECONOMICS AND POLICY, volume 6, issue 1, winter 2012, pp. 45–64, 50.
[138] Cory, Couture, & Kreycik, *supra* note 126 at 13.
[139] UNEP, *Feed-in Tariffs*, *supra* note 124 at 41.
[140] Gustav Resch, et al, *Feed-In Tariffs and Quotas for Renewable Energy in Europe*, CESIFO DICE REPORT 26 (December 2007).
[141] Couture & Cory, *supra* note 136 at 17. "Levelized cost" refers to the lifetime costs of producing electricity from a source divided by the amount of energy produced. DOE Office of Indian Energy, LEVELIZED COST OF ENERGY (LCOE) 3 (undated).
[142] UNEP, *Feed-in Tariffs*, *supra* note 124 at 7.
[143] Couture & Cory, *supra* note 136 at 31.
[144] IEA, *supra* note 61 at 79.
[145] *Id*. at 84. For an example of a policy lacking such stability and the effect on the primary and supporting industries of this uncertainty, *see* the discussion of the wind power production tax credit *infra* at Section III.E.
[146] UNEP, *Feed-in Tariffs*, *supra* note 124 at 70.
[147] Sonal Patel, *The Feed-in Tariff Factor*, POWERMAG (September 1, 2010), available at https://www.powermag.com/the-feed-in-tariff-factor/ (noting that policy makers seek to set FITs rates so as to drive renewable energy deployment).
[148] UNEP, *Feed-in Tariffs*, *supra* note 124 at 38.
[149] Kang, *supra* note 127 at 29.
[150] UNEP, *Feed-in Tariffs*, *supra* note 124 at 40.

inherently differentiates among sources. This supports portfolio diversification.[151] A drawback of this system is that it has higher administrative costs because of the time and expertise required to calculate accurate rates.[152] Because of its assurance of a reasonable return, the cost-based system was the most successful method to incentivize renewable energy, and it was the most common method in Europe.[153]

Cost-based rates utilize one of three methods. The first, a fixed-price system, establishes a guaranteed price for a fixed period, and market fluctuations do not alter the rate.[154] The second, a premium-price method, provides a premium on top of the wholesale market price. To minimize the effect of market fluctuations, some jurisdictions set floors and ceilings for these rates.[155] The third, a spot-market system, sets a guaranteed payment level, and the FIT is determined as the difference between the guaranteed payment level and the wholesale market price.[156]

A second group of methods used to set FITs rates relies upon external considerations. One category considers the fossil fuel costs avoided through utilization of renewable energy.[157] Another approach attempts to set a value for the services provided by the alternative energy source by considering a number of avoided costs and resulting benefits.[158] These factors may include the costs of avoidance of numerous harms: climate change impacts, adverse health effects, air pollutants, and others.[159] Value-based methods are less accurate means to price FITs rates since many of their components are difficult to price accurately and the eventual rate is unlikely to approximate the value of different technologies.[160] On the other hand, value-based approaches are simpler to implement since they do not require technology-by-technology determinations.[161]

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[151] *Id*. at 41.
[152] *Id*.
[153] Couture & Cory, *supra* note 136 at 3.
[154] UNEP, *Feed-in Tariffs*, *supra* note 124 at 44.
[155] *Id*.
[156] *Id*. Another consideration when setting rates involves the availability of other, cost-impacting incentives. For instance, some jurisdictions utilize an investment tax credit, which reduces the net investment cost for projects. *Id*. at 82-83. The presence of such subsidies can reduce the cost of financing. Yoshihiro Yamamoto, *Feed-in Tariffs Combined with Capital Subsidies for Promoting the Adoption of Residential Photovoltaic Systems*, ENERGY POLICY 111 (2017) 312–320, 312. This commensurately lowers the required FIT level. UNEP, *Feed-in Tariffs*, *supra* note 124 at 83.
[157] Couture & Cory, *supra* note 136 at 2.
[158] UNEP, *Feed-in Tariffs*, *supra* note 124 at 38.
[159] *Id*. Minnesota recently developed a similar policy with its value of solar policy. John Farrell, *How to Phase Out Incentives and Grow Solar Energy*, GRIST (May 5, 2014), available at https://grist.org/article/how-to-phase-out-incentives-and-grow-solar-energy/. The system, adopted in 2014, provides that utilities pay a price for solar energy that incorporates the value of avoiding the purchase of electricity from polluting sources, the building of additional power plants, and the additional wear and tear on the electric grid. John Farrell, MINNESOTA'S VALUE OF SOLAR: CAN A NORTHERN STATE'S NEW SOLAR POLICY DEFUSE DISTRIBUTED GENERATION BATTLES? i (2014).
[160] UNEP, *Feed-in Tariffs*, *supra* note 124 at 41.
[161] *Id*. Alternatively, the FITs rate can be based on the market price for electricity. Under this rate structure, generators receive the electricity market price plus a predetermined premium. Kang, *supra* note 127 at 29. Often called a feed-in premium system, it differs from the other methods by being market dependent. A market-dependent method exposes investors to a risk that the market price will not be sufficient to provide the expected return on investment. *Id*. at 30. On the other

FITs can readily facilitate the development of multiple technologies.[162] One particular means to accomplish this is tariff differentiation. This refers to assigning unique rates for separate technologies based upon a range of factors. FITs can range from undifferentiated to highly differentiated, potentially upon a broad range of considerations.[163] Such differentiation can support different technologies and even subsets of technologies (such as onshore and offshore wind). This can assure diversity in technologies with the additional benefit of higher levels of technology penetration.[164] FITs can also differentiate based upon project size, which can support large, industrial facilities as well as small-scale or residential projects.[165] Policies can also differentiate by resource quality, which involves recognition of different resource availability at particular sites. This allows higher prices being provided where resources are less abundant (less windy or sunny, for instance).[166] Other types of differentiation have included technology application (ground- or roof-mounted photovoltaics), ownership type (public or private utility), and local content percentage (to stimulate local industries and employment).[167] Of course, the greater the differentiation of a FIT scheme, the higher the administrative costs that it will necessitate.[168]

A critical issue to address when structuring FITs involves the recovery of the FITs premium. As discussed, FITs typically mandate the payment of a premium exceeding the cost of generating electricity.[169] The utility customers pay the cost of the electricity they use; the question remains of covering the premium. FITs can allocate this cost recovery to ratepayers; alternatively, the state can cover this premium, effectively shifting payment to the taxpayers.[170] Policy makers tend to favor ratepayer payment, viewing it as a more secure and reliable means – payments included as part of a state budget can become targets in budget cutting times.[171]

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hand, analysts have found that market-independent systems provide greater investment security, which tends to lower financing costs. Shahrouz Abolhosseini & Almas Heshmati, *The Main Support Mechanisms To Finance Renewable Energy Development*, RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 40 (2014) 876–885, 879. Although several European nations have recently enacted market-dependent FITs, most countries use market-independent systems. Q.Y. Yan, et al, Overall Review of Feed-In Tariff and Renewable Portfolio Standard Policy: A Perspective of China, EARTH AND ENVIRONMENTAL SCIENCE 40 (2016).

[162] Couture & Cory, *supra* note 136 at v.

[163] UNEP, *Feed-in Tariffs*, *supra* note 124 at 35.

[164] Couture & Cory, *supra* note 136 at 18.

[165] *Id*. at 4.

[166] *Id*. at 18.

[167] UNEP, *Feed-in Tariffs*, *supra* note 124 at 35.

[168] *Id*. at 38.

[169] Christopher Barry, *Feed-in Tariffs: A Policy Mechanism for Renewable Energy Growth*, December 13, 2016, available at http://large.stanford.edu/courses/2016/ph240/barry2/.

[170] UNEP, *Feed-in Tariffs*, *supra* note 124 at 81. States could also choose a hybrid approach, which requires ratepayers to cover a portion of the premium and shifts the remainder to the state budget. *Id*.

[171] *Id*. An example of the unreliability of subsidies incorporated in a state's budget comes from the production tax credit provided by the United States for wind power. Congress allowed it to expire six times before extending it. Steven Ferrey, *Against the Wind—Sustainability, Migration, Presidential Discretion*, 44 COLUMBIA JOURNAL OF ENVIRONMENTAL LAW 341, 358 (2019). *See infra* at Section III.E.

B. Feed-In Tariffs – Illustrative Experiences

While FITs are now widespread, the experiences of several nations – particularly those of Germany, Spain, and China – illustrate many of the policy's strengths and weaknesses. Germany and Spain, the two founders of the FIT scheme, demonstrate FITs at their most effective. However, they also highlight that inherent consequences of successful FITs policies can necessitate substantial modifications, if not outright abandonment. China, on the other hand, illustrates issues that arise when FITs are adopted in larger, regionally diverse countries. Its experience also suggests an approach to avoid some of the problems confronted by Germany and Spain.

1. Germany

As noted previously, in 1979, Germany, adopted a national competition law, mandating purchases of renewable energy at avoided costs.[172] Twelve years later, Germany enacted its FIT, which required the purchase of renewable energy through long-term, fixed-price contracts.[173] Under the German FIT, a surcharge on the bills of residential customers covered the renewable energy subsidies.[174] Germany modified its subsidies several times, most significantly in 2000.[175] The 2000 amendments mandated that FITs contracts last for at least 20-year terms and at prices that exceeded generators' costs.[176]

Germany's feed-in tariff (called the Erneuerbare-Energien-Gesetz (EEG) (Renewable Energy Sources Act) after the 2000 amendments)[177] facilitated a rapid growth in the country's renewable energy generation. In the decade from 1990 to 2000, renewable energy nearly doubled, rising from 3.4% to 6.2% of German

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[172] Davies & Allen, *supra* note 120 at 946.

[173] Michael Ferguson, et al, *Green America: Renewable Standards, Tax Credits, and What's Next*, S & P GLOBAL 13 (October 16, 2017)

[174] Amy Gahran, *Germany's Course Correction on Solar Growth*, GREENTECH MEDIA (November 03, 2016), available at https://www.greentechmedia.com/articles/read/germanys-course-correction-on-solar-growth#gs.12ZPE2s.

[175] Ferguson, *supra* note 173 at 13.

[176] David Suzuki, *Feed-in Tariffs Help Renewable Energy Grow*, STRAIGHT.COM (June 14th, 2016), available at https://www.straight.com/news/717431/david-suzuki-feed-tariffs-help-renewable-energy-grow.

[177] Christoph Böhringer, *The Impact of the German Feed-in Tariff Scheme on Innovation: Evidence Based on Patent Filings in Renewable Energy Technologies*, ENERGY ECONOMICS 67 (2017) 545–553, 545.

electricity production. By 2016, it had jumped to 31.7%.[178] As of 2017, Germany had solar PV capacity of 38 GW,[179] despite having the solar potential of Alaska.[180]

Several aspects of Germany's FIT led to its success. The FIT rate adjusted according to a project's location. This increased the viability of projects in sub-optimal locations, which promoted a more geographically-balanced distribution of wind installations.[181] The FIT also benefitted from relative stability and long investment periods.[182]

Problems, however, began as the overall cost of the FIT rose. To combat the rise in costs, starting with the EEG in 2000, Germany instituted a policy of rate degression. Degression is a FIT policy that decreases FITs rates by predetermined amounts.[183] Reducing FITs rates helps them to reflect technology cost reductions.[184] In addition, degression can be essential to contain overall policy cost as the number of facilities receiving the FITs premium increases in response to lower installation costs.[185]

As the costs of the EEG mounted, Germany instituted more aggressive degression policies. In 2009, it adopted a dynamic degression policy, which considered the quantity of the previous year's installations when determining adjustments to the FITs rates.[186] Two years later, to keep up with rapidly-declining costs, Germany began to adjust its solar PV FITs rates biannually.[187] In 2013, as prices began to fall even faster, Germany began degressing its FITs rates monthly.[188]

At the same time, because of rising total solar subsidies, Germany capped the number of installations that could receive the FITs rate.[189] Nevertheless, the subsidy that ratepayers needed to cover rose substantially. In 2000, the annual EEG subsidy was less than €1 billion; by 2016, it had risen to €26 billion.[190] €25 billion

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[178] *Id*.

[179] For comparison, each nuclear power plant in the United States on average produces about 1 GW of electricity. Office of Nuclear Energy, *How Much Power Does a Nuclear Reactor Produce*?, (February 6, 2018), available at https://www.energy.gov/ne/articles/infographic-how-much-power-does-nuclear-reactor-produce.

[180] Meredith Fowlie, *The Renewable Energy Auction Revolution*, ENERGY INSTITUTE BLOG (August 7, 2017), available at https://energyathaas.wordpress.com/2017/08/07/the-renewable-energy-auction-revolution/.

[181] Lacerda & van den Bergh, *supra* note 103 at 8246.

[182] *Id*.

[183] Couture & Cory, *supra* note 136 at 5. Degression usually applies only to newly-installed facilities. Tae-hyeong Kwon, *Rent and Rent-Seeking in Renewable Energy Support Policies: Feed-in Tariff vs. Renewable Portfolio Standard* (*Rent-Seeking*), RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 44 (2015) 676–681, 679-80.

[184] Couture & Cory, *supra* note 136 at 9.

[185] UNEP, *Feed-in Tariffs*, *supra* note 124 at 65-66.

[186] Tanaka, *supra* note 121 at 6.

[187] Davies & Allen, *supra* note 120 at 957-58.

[188] Bentham Paulos, *The Money Problem with Germany's Renewable Energy Law in 3 Charts*, GREEN TECH MEDIA (June 05, 2014), available at https://www.greentechmedia.com/articles/read/the-money-problem-with-the-german-energiewende-in-3-charts.

[189] Davies & Allen, *supra* note 120 at 958.

[190] Böhringer, *supra* note 177 at 546.

of this appeared as a surcharge on ratepayers' bills, averaging €1,060 per household.[191]

A number of compounding factors caused this jump in the FITs surcharge. Prices for solar panels fell much faster than anticipated. This led to rapidly rising profit margins, which encouraged developers to install even more capacity.[192] Degressing the subsidy more rapidly merely prompted developers to rush to install even more projects before rates fell further. Even though Germany eventually decided to degress rates monthly, the outstanding 20-year guaranteed contracts ensure that Germans will be paying the high FITs rates into the 2030's.[193] Even after its reforms, Germany's residents still pay among the highest electricity rates in Europe.[194]

In 2014, Germany approved a plan largely to replace its FITs with auctions as the primary means to secure new renewable energy contracts.[195] Initially, auctions were compulsory only for ground-mounted PV. Germany amended the EEG again in 2017 to expand the use of auctions for most renewable energy, except for small plants, prototypes, and geothermal energy.[196] Contracts for renewable energy still will have 20-year terms, but the price now is determined through auction rather than by the FITs.[197] Within two years, prices for solar PV dropped by almost 40%.[198] Nevertheless, as of 2018, German consumers were still paying subsidies totaling €27 billion.[199]

2. Spain

In 1994, Spain adopted its FIT. The legislation, Royal Decree 2366/1994, mandated purchases of electricity from designated technologies and set FIT rates of up to 20% above costs.[200] Spain further incentivized solar energy in 2007, when it set the highest rate for PV in the world.[201] Regarding overall renewable energy installations, these policies were quite successful. In 1990, less than 1% of Spain's

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[191] Jeffrey Ball, *Germany's High-Priced Energy Revolution*, FORTUNE (March 2017), available at http://fortune.com/2017/03/14/germany-renewable-clean-energy-solar/.
[192] *Id*.
[193] *Id*.
[194] Suzuki, *supra* note 176.
[195] Corinna Klessmann & Silvana Tiedemann, *Germany's First Renewables Auctions Are a Success, but New Rules Are Upsetting the Market,* ENERGY POST (June 27, 2017), available at http://energypost.eu/germanys-first-renewables-auctions-are-a-success-but-new-rules-are-upsetting-the-market/. Auctions are discussed more fully in Section III.C.3, *infra*.
[196] Norton Rose Fulbright, *German Renewable Energy Act 2017 (EEG 2017) - What You Should Know* (April 2017), available at http://www.nortonrosefulbright.com/knowledge/publications/147727/german-renewable-energy-act-2017-eeg-2017-what-you-should-know.
[197] *Id*.
[198] Klessmann & Tiedemann, *supra* note 195.
[199] Brian Parkin, *German Renewable Subsidy Drops After Wholesale Power Rebound*, BNA ENVIRONMENT & ENERGY REPORT (October 15, 2018).
[200] Davies & Allen, *supra* note 120 at 969.
[201] *Id*. at 975.

electricity was sourced from renewables; by 2009, its share had grown to 25%, and, by 2013, to 54%.[202]

Unlike Germany, Spain did not allow its utilities to pass on the premiums paid for renewable energy to their customers.[203] Instead, it required the utilities to maintain deferral accounts. These accounts enabled the utilities to recover shortfalls from previous years with subsequent years' revenues.[204] However, Spain kept utility prices paid by consumers low. As a result, not only were utilities unable to recoup previous shortfalls, the tariff deficit grew.[205] The 2008 financial crisis compounded problems. Unemployment in Spain rose above 20%, and electricity demand declined commensurately, resulting in excess generating capacity.[206] Spain had hoped that the utilities could sell their tariff deficits as securitized debt, but this became impossible in these new economic conditions.[207] This forced the Spanish government to bail out the utilities and provide backing for the tariff debt.[208] The Spanish government effectively assumed this debt.[209] By 2013, accumulated debt had ballooned to €26 billion.[210]

Spain began introducing a series of measures to rein in its FIT. In 2012, it modified its compensation scheme, no longer basing it upon FITs rates, but instead assuring a "reasonable profitability" based upon a company's assets.[211] Critically, Spain applied its reforms retroactively. Consequently, older facilities that were constructed in anticipation of receiving FITs rates stopped receiving subsidies altogether.[212]

Not surprisingly, such retroactive changes prompted litigation, but, importantly, on two fronts. Domestic investors brought suits in Spanish courts, while international investors were able to pursue their claims in the International Centre for Settlement of Investment Disputes (ICSID).[213] The Spanish courts upheld the FITs cuts.[214] The international court, however, sided with the investors. Investors have filed 26 cases in the ICSID over Spain's altering of its FITs

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[202] *Id*. at 979.
[203] Institute of Energy Research (IER), *Spain Halts Feed-In-Tariffs for Renewable Energy* (April 9, 2012), available at https://www.instituteforenergyresearch.org/renewable/wind/spain-halts-feed-in-tariffs-for-renewable-energy/.
[204] *Id*.
[205] Davies & Allen, *supra* note 120 at 981.
[206] IER, *supra* note 203.
[207] Davies & Allen, *supra* note 120 at 981.
[208] IER, *supra* note 203.
[209] Davies & Allen, *supra* note 120 at 977.
[210] Carmen Otero García-Castrillón, SPAIN AND INVESTMENT ARBITRATION: THE RENEWABLE ENERGY EXPLOSION 5 (2016).
[211] Davies & Allen, *supra* note 120 at 978.
[212] *Id*. at 979.
[213] García-Castrillón, *supra* note 210 at 6.
[214] *Id*. at 10.

contract.[215] Spain has already lost several of these cases, with the judgments currently totaling in excess of $590 million.[216]

Although the Spanish FIT engendered substantial financial burdens, it did accomplish its purpose. Not only did renewable energy deployments take off under the FIT,[217] the FIT established conditions that enabled continued renewable energy investment. Indeed, in the past three years, Spain has added 12 GW of solar power, an amount that exceeded its remaining 9 GW of coal.[218] More notably, it started installing 5 GW of solar in 2018 despite the absence of subsidies.[219]

3. China

In 2006, China enacted the framework for its FIT, and, three years later, it established a specific FIT to support wind power.[220] In 2011, China enacted a series of FIT policies to further support solar PV.[221] This accelerated investment in solar, with annual installations rising from less than 5 GW in 2011 to nearly 35 GW in 2016.[222] Initially, China's program provided a premium payment for renewable sources, and the government paid the premium.[223] Subsequently, in 2009, it imposed a surcharge on retail electricity rates to finance the FIT.[224]

Despite the rapid rise in PV installations, China encountered some issues in the application of its FIT program. China and its FIT program are distinct from European countries and their policies in several ways. First, China is a much larger country, and its renewable energy resources are unevenly distributed in the north, northwest, and south.[225] Conversely, the developed areas of the country are in central and eastern China.[226] As discussed below, these disparities would create implications for China's FIT structure. Second, unlike its contemporaries, the

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[215] Blanca Díaz López, *Spain Loses Its First Renewable Energy Case in International Courts*, PV MAGAZINE (May 5, 2017), available at https://www.pv-magazine.com/2017/05/05/spain-loses-its-first-renewable-energy-case-in-international-courts/.
[216] These decisions include 9REN Holding S.a.r.l v. Kingdom of Spain, ICSID Case No. ARB/15/15 ($46,958,243) https://www.italaw.com/cases/7374; Eiser Infrastructure Limited and Energía Solar Luxembourg S.à.r..l. v. Kingdom of Spain, ICSID Case No. ARB/13/36 ($140,757,760) ; Masdar Solar & Wind Cooperatief U.A. v. Kingdom of Spain, ICSID Case No. ARB/14/1 ($75,644,310) https://www.italaw.com/cases/6608; NextEra Energy Global Holdings B.V. and NextEra Energy Spain Holdings B.V. v. Kingdom of Spain, ICSID Case No. ARB/14/11 ($327,145,274) https://www.italaw.com/cases/2585;
[217] Davies & Allen, *supra* note 120 at 979.
[218] Reed Landberg, *Spain Says 5 Gigawatts of Subsidy-Free Solar Farms Being Built*, BNA Environment & Energy Report (October 1, 2018).
[219] *Id*.
[220] Carolin Schenuit, et al, MONEY WELL SPENT: THE ECONOMIES OF SUPPORT POLICIES FOR RENEWABLES 38 (2018).
[221] Liang-Cheng Ye, João F.D. Rodrigues, & Hai Xiang Lin, *Analysis of Feed-in Tariff Policies for Solar Photovoltaic in China 2011–2016*, APPLIED ENERGY 203 (2017) 496–505, 496-97.
[222] *Id*. at 498.
[223] Schenuit, et al, *supra* note 220 at 38.
[224] *Id*.
[225] Yan, et al, *supra* note 161 at 7.
[226] Ye, Rodrigues, & Lin, *supra* note 221 at 502.

Chinese FIT did not impose an automatic degression. It did incorporate a 30-month tariff adjustment period,[227] but this contrasts greatly to Germany's eventual adjustment period of one month.[228] As in Europe, solar PV prices in China declined rapidly, leading to highly profitable FITs rates later in the period.[229] The Chinese FIT policies did incentivize solar PV, but developers built a substantial portion of the facilities in the western portion of China. This area is rich in solar resources, but it was relatively undeveloped and lacked transmission lines to high-consumption provinces.[230] Unused wind and solar capacity worsened after 2014.[231] In different regions of China, wasted wind power reached 21% and unused solar neared 20%.[232]

To address this problem, China regionalized its FIT system. Under this approach, installations in areas receiving higher levels of solar radiation earned lower tariffs.[233] In addition, China also imposed quotas (caps) on the amount of PV installations built in each region. Installations that exceeded the quota would not receive the region's FIT rate.[234] However, China does not utilize a hard cap. Instead, the central government sets the quotas, but it allows local governments to approve developments. Local governments, of course, are incentivized to approve projects to promote local economies. Consequently, they typically approved more projects than their quota targeted.[235]

As elsewhere, the Chinese FIT began to require substantial modification. Public support for the FIT began to wane, and tens of billions of yuan of FITs subsidies were not provided.[236] By 2017, China's deficit exceeded $16 billion.[237] In 2017, China implemented a trial renewable portfolio standard (RPS) for wind

[227] *Id*. at 497.
[228] Paulos, *supra* note 188.
[229] Ye, Rodrigues, & Lin, *supra* note 221 at 503.
[230] *Id*. at 497.
[231] Yuki Yu, *China RPS Won't Include Subsidy Cuts for Existing Projects*, RECHARGE NEWS (August 13, 2018), available at http://www.rechargenews.com/wind/1553961/china-rps-wont-include-subsidy-cuts-for-existing-projects?utm_medium=email&utm_source=free_article_access&utm_content=227641456.
[232] Brian Publicover, RECHARGE NEWS (January 12, 2017), available at http://www.rechargenews.com/wind/1206551/china-set-to-rein-in-provinces-over-energy-policy-in-2017.
[233] Ye, Rodrigues, & Lin, *supra* note 221 at 497.
[234] *Id*. at 498.
[235] *Id*. at 502.
[236] Qi Zhang, et al, *Substitution Effect of Renewable Portfolio Standards and Renewable Energy Certificate Trading for Feed-in Tariff* (*Substitution Effect*), APPLIED ENERGY 426-435, 426 (2018).
[237] Becky Beetz, *New Renewable Funding Mechanisms Higlighted For China – Report*, PV MAGAZINE (December 13, 2018), available at https://www.pv-magazine.com/2018/12/13/new-renewable-funding-mechanisms-higlighted-for-china-report/.

power and solar PV.[238] The RPS applies to 31 cities and provinces,[239] though full implementation will not occur for at least five years.[240]

The experiences of these three countries illustrate the success that FITs have had in promoting renewable energy; they also provide cautionary tales about potential problems that might arise. Consistent with the S curve pattern, slow technological development was followed by explosive growth. Although the cost of renewable energy dropped dramatically, the long-term commitment that fostered that growth became so burdensome that it necessitated policy changes, including the elimination of the FIT.

C. Feed-In Tariffs – Long Term Effects

1. Problems

Despite the profound success of FITs, or possibly because of it, countries utilizing them have eventually encountered difficulties. Nations who have successfully employed FITs to incentivize renewable energy installation during the early adoption stage have often needed to restrict or abandon these policies as the technologies advance through the take-off stage. A review of these developments suggests that the dynamics of the S curve provide especially important insights for the utilization and modification of FITs policies.

As noted, FITs have contributed substantially to the growth of renewable energy throughout the globe.[241] The experiences of Germany and Spain have demonstrated, however, the long-run effects of FITs can be problematic. FITs create market distortions that, as the targeted technologies begin to take off, require modification of the FITs or transition to alternative policies.[242]

Although FITs are very effective in their short- and intermediate-term impacts on new technologies, a number of concerns will typically arise over their long-term implementation.[243] Long-run utilization of FITs can cause fiscal burdens, market distortions, and decreased innovation.[244] Indeed, FITs caused

[238] Yuzhuo Zhang, et al, *The Development of the Renewable Energy Power Industry under Feed-In Tariff and Renewable Portfolio Standard: A Case Study of China's Photovoltaic Power Industry* (Development), SUSTAINABILITY 2 (2017). A discussion of RPSs appears *infra* at Section III.D.
[239] Yu, *supra* note 231.
[240] Publicover, *supra* note 232. Interestingly, the Chinese government's initial draft proposal planned to impose a Spain-like retroactive cut to FITs subsidies. Specifically, it proposed to eliminate FITs subsidies for production exceeding an annual limit. Yu, *supra* note 231. Instead, in May 2018, China decided to award subsidies only to solar projects staying within particular quota limits. Schenuit, et al, *supra* note 220 at 39.
[241] UNEP, *Feed-in Tariffs*, *supra* note 124 at 5.
[242] Lo, *supra* note 126.
[243] Yan, *supra* note 161 at 2.
[244] Hongwei Wang, *Analysis of the Policy Effects of Downstream Feed-In Tariff on China's Solar Photovoltaic Industry*, ENERGY POLICY 95 (2016) 479–488, 486. Also, *see supra*, Section III.C.1.

heavy financial burdens throughout the globe.[245] An aspect of FITs that constitutes one of their strengths – their contract requirements – inevitably leads to these problems. FITs typically require 15-20 year contracts set at premium levels.[246] A problem inherent with FITs, however, is that governments establish the tariff levels, while the costs of the technologies result from market forces.[247] Cost declines are one of the expected benefits of FITs.[248] For example, wind power price reductions resulted from a number of factors triggered by FITs, including economies of scale, technological improvements, and learning by doing.[249] Nevertheless, FITs mandate the purchase of electricity at premium rates potentially decades into the future. Consequently, declines in technology costs stimulate booms in installations to take advantage of the resulting profit margins, thereby triggering excessive subsidy burdens.[250]

These surcharges, resulting from decades-long commitments, must be passed on either to ratepayers or to taxpayers.[251] Such surcharges plagued the FITs utilized by Germany and Spain, respectively.[252] Consequently, both nations, whose FITs were models for other countries, abandoned their FITs.[253] The inevitability of such problems was noted by Professors Davies and Allen, who wrote, "the paradox inherent in feed-in tariffs is that they are designed to gradually self-destruct."[254] While a substantial and growing surcharge is usually inevitable (assuming FITs accomplish their intended purpose of reducing costs and thereby stimulating installations), as discussed below, jurisdictions can design FITs to compensate for these developments.

Interestingly, in 2012 South Korea replaced its FIT with an RPS.[255] South Korea instituted this change for several reasons. The country paid its FIT subsidies through its national budget.[256] Consequently, South Korea regularly confronted

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245 Zhang, *Substitution Effect*, *supra* note 236 at 433.
246 Couture & Cory, *supra* note 136 at 17.
247 Schenuit, et al, *supra* note 220 at 39. Indeed, critics have pointed to the reliance of FITs upon governments instead of markets to set tariff levels as one of the policy's greatest shortcomings. Nolden, *supra* note 79 at 6.
248 Mormann, *Clean Energy Federalism*, *supra* note 132 at 1662. Especially for technologies that are at low production levels, the long-term unit cost curve demonstrates increasing returns to scale. This pattern was apparent both for wind and solar PV technologies. Rao & Kishore, *supra* note 54 at 1073; *see also* Figure 2. Indeed, while funding for R&D was initially the most important factor for cost reduction for solar PV, scale economies became more significant in lowering costs. Kavlak, McNerney, & Trancik, *supra* note 100 at 700.
249 Davies & Diaz-Rainey, *supra* note 55 at 1228.
250 Schenuit, et al, *supra* note 220 at 39. *See also* Nolden, *supra* note 79 at 6 (noting that poor economic forecasting by governements can result in mismatching of tariffs and costs, resulting in "gold rushes" or "'boom and bust' cycles").
251 UNEP, *Feed-in Tariffs*, *supra* note 124 at 81.
252 *See supra* Sections III.C.1.
253 *Id*.
254 Davies & Allen, *supra* note 120 at 997.
255 Research Office Legislative Council Secretariat, FEED-IN TARIFF FOR SOLAR POWER IN SELECTED PLACES 5 (undated). South Korea established its FIT in 2002. Kang, *supra* note 127 at 20.
256 Davies & Allen, *supra* note 120 at 985.

budget overruns caused by its FIT.[257] Particularly problematic was a rapid increase in subsidies for solar photovoltaic.[258] While the FIT was successful in incentivizing a number of suppliers to install solar, this imposed significant costs.[259] Moreover, despite its success with solar, overall the FIT underperformed. Specifically, South Korea sought to raise renewable energy's share of total electricity to 8%, but it reached only 3%.[260] Accordingly, the country switched to an RPS in part to impose a more results-oriented policy.[261] The move worked, as renewable energy installations increased three fold during the succeeding five years when compared to the previous decade's deployment under the FIT.[262]

Besides their well-documented financial burdens, FITs suffer from another concern: their continued promotion of technological innovation is limited. If set too high, subsidy policies, such as FITs, can encourage deployment of expensive and inefficient technologies, locking-in these methods and failing to incentivize less mature technologies.[263] Moreover, since high-cost technologies receive profitable returns on investments, FITs remove a primary incentive to innovate and reduce costs.[264] Eliminating – or at least reducing – subsidies, such as FITs, forces industry to lower costs.[265] Because of the cost-plus-profit structure used by most FITs, they encourage exploitative behavior (increasing production of existing technologies) over inventive activities (investing in research and development to increase efficiencies and reduce costs).[266]

2. Making FITs Work

To avoid the financial burdens inevitable with FITs, policy makers can incorporate provisions to minimize or avoid their effects. Because of the market changes FITs produce, FITs policies inevitably need to be adjusted over time.[267]

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[257] Tae-Hyeong Kwon, RENEWABLE PORTFOLIO STANDARD IN SOUTH KOREA: A SHORT POLICY REVIEW (*RPS in South Korea*) 1 (undated). The switch to an RPS had several financial implications for the government. First, premium costs for renewable energy would be borne by ratepayers. Second, an RPS's inherent incentivizing of least-cost alternatives would lower the overall costs of renewable energy deployment. Ryan Wiser, Galen Barbose, & Edward Holt, *Supporting Solar Power in Renewables Portfolio Standards: Experience from the United States*, ENERGY POLICY 39 (2011) 3894–3905, 3896. Finally, an RPS's requirement to increase the share of renewable energy over time would encourage more predictable renewable energy growth. Davies & Allen, *supra* note 120 at 996. The latter is consistent with the South Korean government's interest in enacting a more results-oriented policy. Kang, *supra* note 127 at 11.
[258] Kwon, *RPS in South Korea*, *supra* note 257 at 3.
[259] Kang, *supra* note 127 at 20.
[260] *Id*. at 11.
[261] *Id*.
[262] Lo, *supra* note 126.
[263] Böhringer, *supra* note 177 at 546.
[264] *Id*.
[265] Schenuit, et al, *supra* note 220 at 39.
[266] Böhringer, *supra* note 177 at 552.
[267] *Id*. at 1003. As the authors note, if FITs do not evolve, "they risk becoming ineffective, overly expensive, or unwanted." *Id*. Italy provides another example of a country that failed to reduce its

Such adjustments need to be proactive.[268] If not adjusted timely, the disparity between technology costs and tariffs fosters "rent-seeking"[269] behavior, sparking a rise in the number of installations as the FITs subsidy increases.[270]

FITs can avoid or at least minimize these consequences either by anticipating changes or adjusting their tariffs as conditions change. At the time that FITs are established, policy makers can select from a range of options to adjust the FITs subsidy, ranging from systems that are fully automatic to methods that require regulator decisionmaking.[271] Policy makers can anticipate market changes by structuring planned degressions in their FITs tariffs by basing them on the number of installations or overall cost.[272] Often, such policies utilize predetermined triggers to initiate automatic adjustments. Typical triggers include the passage of a specified period of time, the achievement of specific capacity or generation levels, or total policy costs.[273] Alternatively, policy makers can design their FITs to require regulators to evaluate market conditions periodically and to adjust their tariffs accordingly.[274]

Because FITs control price rather than quantity,[275] the amount of actual installations under a FIT is often difficult to forecast.[276] Thus, when the FITs subsidies increase because costs have declined while the tariff has remained flat, adjustment mechanisms help to control the volume of projects eligible for the

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subsidy in a timely manner and suffered its consequences. From 2007 to 2011, the cost of solar PV systems declined substantially while the country made no changes to its FITs rates. This led to a significant rise in the number of PV installations, prompting a commensurate rise in the financial burden of the Italian FIT. Tanaka, *supra* note 121 at 6. The FIT charge constituted 18% of the average household's bill, for an annual total exceeding €10 billion. V. Di Dio, S. Favuzza, et al, *Critical Assessment of Support for the Evolution of Photovoltaics and Feed-In Tariff(s) in Italy*, SUSTAINABLE ENERGY TECHNOLOGIES AND ASSESSMENTS 9 (2015) 95–104, 101.

[268] Davies & Allen, *supra* note 120 at 1004.

[269] "Rents" in this context are windfall profits. Kwon, *Rent-Seeking*, *supra* note 183 at 678. They arise when the same price is paid for a good with a declining cost of production. Vivid Economics, ADVANCE MARKET COMMITMENTS FOR LOW-CARBON DEVELOPMENT: AN ECONOMIC ASSESSMENT 48 (2009).

[270] Kwon, *RPS in South Korea*, *supra* note 257 at 6.

[271] UNEP, *Feed-in Tariffs*, *supra* note 124 at 65-66.

[272] Mormann, *Clean Energy Federalism*, *supra* note 132 at 1662, n.231. Professor Mormann notes, for instance, that Germany's FIT incorporated standard degressions that anticipated cost reductions, while California's FIT automatically adjusted its FIT rates lower (or higher) if technology deployments exceeded (or failed to meet) expectations. *Id*. An added advantage of degressions is that they provide incentives to innovate to reduce costs and maintain profit margins. Indeed, evidence indicates that Germany's degression stimulated R&D investments. Pablo del Rıo & Mercedes Bleda, *Comparing the Innovation Effects of Support Schemes for Renewable Electricity Technologies: A Function of Innovation Approach*, ENERGY POLICY 50 (2012) 272–282, 277.

[273] UNEP, *Feed-in Tariffs*, *supra* note 124 at 66.

[274] Couture & Cory, *supra* note 136 at 5. For example, Spain chose to adjust its FITs rates annually. *Id*.

[275] Nurcan Kilinc-Ata, *The Evaluation of Renewable Energy Policies Across EU Countries and US States: An Econometric Approach*, ENERGY FOR SUSTAINABLE DEVELOPMENT 31 (2016) 83–90, 84.

[276] Nigel Martin & John Rice, *Solar Feed-In Tariffs: Examining Fair And Reasonable Retail Rates Using Cost Avoidance Estimates*, ENERGY POLICY 112 (2018) 19–28, 19.

tariff.[277] Unfortunately, these approaches implicate a tension inherent in FITs between maintaining price stability and adjusting tariffs to compensate for changing circumstances.[278] Injecting uncertainty through price adjustments for as little as a few years into the future can increase the perceived riskiness for financiers.[279] Policy stability and transparency better supports investors' security.[280] The detrimental effect of tariff adjustments can be minimized by increasing the transparency of the process – such as setting predetermined periods for adjustments or tying adjustments to levels of deployment.[281]

Thus, some adjustments are available within the FITs system. Nevertheless, most nations chose to replace their FITs partially or wholly with other policies.

3. Transitioning to Auctions

To minimize the financial impacts of FITs, jurisdictions have turned to another mechanism – tenders. As renewable energy technologies have matured, their costs no longer impede investment. Consequently, the FITs subsidy becomes unnecessary to encourage deployment of these technologies.[282] Furthermore, perpetuating FIT subsidies during a technology's take-off stage increases their financial burden substantially.[283] Accordingly, a number of countries have turned to a process first used decades previously to secure renewable energy contracts – tenders.[284] Tenders (also called "competitive bidding,"[285] "reverse auctions,"[286] or just "auctions"[287]) enable governments to control the costs of renewable energy deployment. Governments determine the amount of capacity to be built, open the contracts for these installations to bidders, and then contract with a low bidder, who agrees to build the identified capacity.[288] Some tenders award the contract to the lowest bidder, while others may use multiple criteria to select winners.[289]

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[277] UNEP, *Feed-in Tariffs*, *supra* note 124 at 69.
[278] Stokes, *supra* note 131 at 490.
[279] Cory, Couture & Kreycik, *supra* note 126 at 12.
[280] UNEP, *Feed-in Tariffs*, *supra* note 124 at 60.
[281] IEA, *supra* note 61 at 81. Of course, including adjustments with triggers or market reviews requires additional administrative infrastructure to support these policy shifts. UNEP, *Feed-in Tariffs, supra* note 124 at 69.
[282] Herman K. Trabish, *RIP FITs: As US feed-in tariffs fade, adopting elements could spur solar growth*, UTILITY DIVE (July 18, 2016), available at . https://www.utilitydive.com/news/rip-fits-as-us-feed-in-tariffs-fade-adopting-elements-could-spur-solar-gr/422727/.
[283] Schenuit, et al, *supra* note 220 at 39.
[284] In the 1990's under its Non Fossil Fuel Obligation (NFFO), the United Kingdom accepted bids for electricity generation from non-fossil fuel sources, including renewable energy. Fell, *supra* note 114 at 3.
[285] REN21, *supra* note 123 at 122-23.
[286] Kilinc-Ata, *supra* note 275 at 84.
[287] REN21, *supra* note 123 at 122-23.
[288] Kilinc-Ata, *supra* note 275 at 84. Tenders may include ceiling prices to signal the maximum rate that will be accepted, thereby assuring policy costs. Schenuit, et al, *supra* note 220 at 16.
[289] *Id*. at 9. Additional criteria typically involve factors such as local industrial development, project lead time, or geographic distribution of installations. *Id*. at 18.

Government tenders have sought fulfillment by specific technologies or groups of technologies, or they have been technology neutral.[290]

The use of tenders to source renewable energy has increased significantly. Nations both in Europe and Asia have utilized tenders in recent years. A number of European nations, including many renewable energy leaders, have turned to tenders. In 2015, Germany, the country that developed one of the model FITs, replaced its tariff program with auctions.[291] France, Denmark and The Netherlands, among many others, are now using tenders as a primary means to add renewables.[292] Some of the largest tenders, however, occurred in Asian countries, including China and India; Japan also has scheduled its own tenders.[293] Overall, the number of countries using auctions has grown from 6 in 2005 to 67 in 2016.[294]

Not only do tenders avoid the burden of FITs subsidies, they can reduce renewable energy costs. Tenders, by their nature, encourage price competition.[295] In a typical tender system, developers bid to sell electricity they will generate from a specified technology.[296] Thus, a primary function of tenders is to establish prices for electricity generated from particular technologies and to award contracts.[297] One of the key advantages of tenders is that they determine prices through competitive price discovery rather than by administrative determination.[298] Tenders, accordingly, are not truly support instruments, but instead they constitute a design element that can work with support mechanisms (such as a FIT or grid-connection policies).[299] Besides assisting with price discovery, another benefit of

[290] Malte Gephart, Corinna Klessmann & Fabian Wigand, *Renewable Energy Auctions – When Are They (Cost-)Effective?*, ENERGY & ENVIRONMENT 2017, Vol. 28 (1–2) 145–165, 148.
[291] REN21, *supra* note 123 at 122.
[292] *Id*. at 123. Tenders currently constitute the fastest-growing form of renewable energy procurement in the United Kingdom. *Id*. at 122-23.
[293] *Id*. at 123.
[294] IRENA, RENEWABLE ENERGY AUCTIONS: ANALYSING 2016 16 (2017). Typically, countries schedule tenders periodically. UNEP, *Feed-in Tariffs*, *supra* note 124 at 12.
[295] Toby D. Couture, et al, THE NEXT GENERATION OF RENEWABLE ELECTRICITY POLICY: HOW RAPID CHANGE IS BREAKING DOWN CONVENTIONAL POLICY CATEGORIES 5 (2015).
[296] UNEP, *Feed-in Tariffs*, *supra* note 124 at 12.
[297] Couture, et al, *supra* note 295 at 12. Another value of tenders is that they provide governments with a better ability to control the installation of renewable energy and the particular mix of resources installed. Schenuit, et al, *supra* note 220 at 11.
[298] IEA, *supra* note 61 at 132. By determining prices through direct competition, tenders help avoid the windfall profits, or rents, possible when prices fall faster than tariffs adjust. Schenuit, et al, *supra* note 220 at 11. This price discovery process also not only informs the current price, but also the historic trend informs future auction prices. IRENA, *supra* note 294 at 17.
[299] Schenuit, et al, *supra* note 220 at 9. Jurisdictions utilize tenders in a number of different capacities relative to FITs. In many instances, tenders replace their FITs. Oscar Fitch-Roy, David Benson & Bridget Woodman, *Policy Instrument Supply and Demand: How the Renewable Electricity Auction Took over the World*, POLITICS AND GOVERNANCE (2019), Vol. 7, Issue 1, Pages 81–91, 82. In others, they merely supplement FITs policies. Paolo Cozzi, ASSESSING REVERSE AUCTIONS AS A POLICY TOOL FOR RENEWABLE ENERGY DEPLOYMENT 30 (2012). In some instances, countries use tenders side-by-side with FITs, typically awarding contracts for larger contracts through tenders while using FITs to support smaller projects (and, typically, smaller developers). REN21, *supra* note 123 at 132.

tenders is that they reduce procurement costs.[300] By forcing developers to bid for power-purchase contracts to sell electricity into the grid, tenders incentivize developers to reduce costs to secure contracts for their projects.[301]

Despite the popularity of tenders, critics have raised several concerns about their use. A primary concern is that tenders limit the volume of new installations.[302] This in part results from the contrasting natures of tenders and the mechanism often preceding them, FITs. A critical benefit of FITs is that any investor in a qualifying project is assured of receiving the tariff for generated electricity.[303] Conversely, tenders award contracts only to those projects necessary to achieve a particular installation or budget goal.[304] Indeed, several nations have turned to tenders to slow down the installation of renewable energy resources. Countries with mature solar markets, for instance, have used tenders to address subsidy budget deficits, market saturation, and grid management concerns.[305]

A critical distinction of tenders from FITs is that tender systems reduce investor certainty. Since tenders cannot assure investors of securing contracts unless they submit a winning bid, tenders inject uncertainty into the development phase of a project.[306] Not only do tenders instill doubt, they also impose new

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[300] Fowlie, *supra* note 180.

[301] Brian Parkin, *Germany Pits Solar Against Wind for First Time in Power Auction*, BNA ENVIRONMENT & ENERGY REPORT (Feb. 21, 2018).

[302] Fell, *supra* note 114 at 1 (stating, actually, that "tenders massively curb the expansion rates of renewable energies"). An initial concern regarding the replacement of FITs with tenders was the latter's realization rates. Low realization rates – awarded bidders failing to generate the amount of electricity contracted – characterized tenders. Jan Kreiss, Karl-Martin Ehrhart, & Marie-Christin Haufe, *Appropriate Design of Auctions for Renewable Energy Support – Prequalifications and Penalties*, ENERGY POLICY, Vol. 101, (February 2017) 512-520, 512. This results from bidders submitting low bids that do not cover project costs. *Id*. For example, early tenders suffered from realization rates below 40% (38% under the UK's NFFO program from 1990 to 1998, 30% for a geothermal auction by The Netherlands' in 2011, and 30% for an onshore wind auction in Brazil in 2009-10). Gephart, Klessmann & Wigand, *supra* note 290 at 151. The low realization rates have had different causes. For instance, in the United Kingdom, tenders utilized low financial prequalification standards; in Brazil, conversely, the unavailability of grid connections rendered timely satisfaction of realization requirements impossible. Kreiss, Ehrhart, & Haufe, *supra* note 302 at 513.

Governments can avoid the problem of low realization rates, however, by imposing prequalification requirements or penalties. *Id*. Prequalification requirements may include satisfaction of general criteria (such as experience, technical ability, or financial strength) or fulfillment of project-specific actions (such as submission of a land-use plan or a feasibility study). *Id*. at 512-13. Penalties can include lower levels of financial support, a shortened support period, termination of the contract, or exclusion from future auctions. *Id*. at 513. Accordingly, more recent realization rates have exceeded 90%. Sandra Enkhardt, *Germany Reports High Realization Rate for PV Projects Selected in Auctions*, PV MAGAZINE (January 9, 2018), available at https://www.pv-magazine.com/2018/01/09/germany-reports-high-realization-rate-for-pv-projects-selected-in-auctions/.

[303] Schmalensee, *supra* note 137 at 50.

[304] IRENA, *supra* note 294 at 17.

[305] Sonal Patel, *More Countries Banking on Competitive Auctions over Subsidies to Stimulate Renewables* (*More Countries Banking*), POWERMAG (January 3, 2018), available at https://www.powermag.com/more-countries-banking-on-competitive-auctions-over-subsidies-to-stimulate-renewables/.

[306] IEA, *supra* note 61 at 132.

administrative costs in the form of bid preparation.[307] This can be especially problematic for smaller developers.[308] Finally, tenders tend to favor a few, dominant players over smaller participants. Several characteristics of tenders – including administrative and financial requirements – discourage engagement by small actors.[309]

Nevertheless, a number of countries have begun using tenders to secure renewable energy production. France was one of the first countries to do so. In 2001, it applied FITs to projects under 12 MW and tenders to larger projects.[310] Ten years later, France extended its tender program to smaller projects and broadened it to cover rooftop solar.[311] Both FITs and tenders were successful. In fact, as of 2014, 38% of the country's solar PV capacity resulted from its FIT while the remaining 62% derived from tenders.[312]

Another country now relying upon tenders is Germany. As previously discussed, in response to its high electricity costs, Germany abandoned its FIT.[313] In its place, Germany instituted tenders for renewable energy procurement.[314] It started with auctions for solar power in 2015.[315] Germany then added tenders for onshore wind, offshore wind, and biomass.[316] In the eleven solar auctions Germany has conducted since 2015, the price fell steadily from 9.17 cents/kWh to 4.59 cents/kWh in less than three years.[317] Furthermore, the realization rate of the first four tenders (for which contract completion data is available) ranged between 90% and 99.9%.[318] The tenders have seen such success that Germany's parliament approved legislation to expand the country's use of auctions. In fact, the parliament expects renewable energy's share of Germany's electricity production to rise from 38 percent to 65 percent by 2030.[319] Furthermore, tenders have achieved their intended goal of controlling renewable energy costs. After the adoption of tenders, renewable energy prices fell to levels comparable to those of fossil fuel sources.[320]

Following this lead, other countries have adopted tenders as well. The two largest developing countries, China and India, have decided to use tenders to secure

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[307] Schenuit, et al, *supra* note 220 at 11.
[308] *Id*.
[309] Fell, *supra* note 114 at 9. On the other hand, Fell acknowledges that tenders can be helpful in procuring investments from large investors for more sizeable projects that help reduce costs. *Id*. at 18.
[310] Couture, et al, *supra* note 295 at 5. Advantages of this "layered" approach include enabling better control over market segment development and ensuring growth of multiple project size categories. *Id*. at 8.
[311] *Id*.
[312] *Id*. at 10.
[313] Fowlie, *supra* note 180.
[314] *Id*.
[315] Schenuit, et al, *supra* note 220 at 24.
[316] Klessmann & Tiedemann, *supra* note 195.
[317] Schenuit, et al, *supra* note 220 at 24.
[318] *Id.*
[319] Brian Parkin, *German Wind, Solar Tenders Expand as Sights Set on Coal's Exit*, BNA ENVIRONMENT & ENERGY REPORT (November 30, 2018).
[320] Vaishnavi Chandrashekhar, *As Subsidies Wane, Market Forces Drive the Growth of Renewables*, GREENBIZ (July 16, 2018), available at https://www.greenbiz.com/article/subsidies-wane-market-forces-drive-growth-renewables.

future renewable energy installations. In 2018, China announced that it would end its FIT for utility-scale projects and require the use of tenders to set their prices.[321] India also has turned to tenders to increase its renewable energy installations. Specifically, it will use tenders to secure 500 GW of renewable energy generation capacity by 2028.[322]

Several jurisdictions and utilities in the United States have begun turning to tenders, too. Since 2010, California has enabled investor-owned utilities to use tenders to procure RPS-eligible renewable energy production from small producers.[323] In addition, the PJM Interconnection[324] and utilities in Arizona, Massachusetts, and Nevada, have all recently enacted tenders.[325]

Tenders have helped to lower the costs of renewable energy installations. They have established lower prices for solar PV, onshore wind, and offshore wind.[326] For projects coming online by 2023, costs range from 45% to 67% lower.[327] Thus, tenders have provided a means to contain costs in the take-off stage after FITs have successfully promoted these technologies.

D. Renewable Portfolio Standards

1. A Brief Review

RPSs have also played a prominent role in incentivizing renewable energy deployment. A quick review of RPSs follows to enable a comparison to FITs,

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[321] Emma Foehringer Merchant, *China's Bombshell Solar Policy Shift Could Cut Expected Capacity by 20 Gigawatts*, GREENTECH MEDIA (June 06, 2018), available at https://www.greentechmedia.com/articles/read/chinas-bombshell-solar-policy-could-cut-capacity-20-gigawatts#gs.pfkhc6. China first implemented a tender in 2003, six years before it established its FIT. A wide variance in bid prices, however, reflected the industry's still immature state. Schenuit, et al, *supra* note 220 at 40.

[322] *Renewables Continue To Add Capacity Despite Glut*, ENERGY NEWS MONITOR (May 13 2019), available at https://www.orfonline.org/research/energy-news-monitor-volume-xv-issue-48-50758/. Brazil, another developing country, has also turned to tenders for new wind installations, setting contract prices that represent a 60% reduction from its FITs rates. Gephart, Klessmann & Wigand, *supra* note 290 at 155.

[323] California Public Utilities Commission, Renewable Auction Mechanism, available at http://www.cpuc.ca.gov/renewable_auction_mechanism/.

[324] PJM Interconnection is a regional transmission organization that coordinates wholesale electricity transactions in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. PJM, *Who We Are*, available at https://www.pjm.com/about-pjm/who-we-are.aspx.

[325] Schenuit, et al, *supra* note 220 at 27.

[326] IEA, *Have the prices from competitive auctions become the "new normal" prices for renewables?* (February 4, 2019), available at https://www.iea.org/newsroom/news/2019/february/have-the-prices-from-competitive-auctions-become-the-new-normal-prices-for-.html.

[327] *Id*. A number of factors, however, determine the prices established by the auctions and their eventual success in securing the electricity sought. These include any land acquisition costs, resource quality, and project size. IRENA, *supra* note 294 at 21.

leading to a proposal to incorporate aspects of both policies to accelerate CDR development.[328]

RPSs implement a different approach from that used by FITs, and they have unique strengths and weaknesses. RPSs mandate that electricity producers must generate or purchase pre-established minimum percentages of their power from designated (usually renewable) sources.[329] The generation of electricity from such sources is recognized through the provision of renewable energy credits (RECs).[330] RPSs then utilize markets to set prices for renewable energy by allowing trading of these RECs.[331] The trading of RECs in a market fosters price competition.[332] RPSs have been popular and successful in incentivizing renewable energy development. While RPSs are not as widespread as FITs, as of 2017, at least 67 countries had set RPS-like targets for renewable capacity or generation.[333]

A major distinction between FITs and RPSs involves the certainty for developers of their return on investment.[334] FITs, of course, guarantee the purchase of electricity generated by qualified sources.[335] Power producers in RPS jurisdictions, however, submit proposals through competitive solicitations.[336] A competitive solicitation can impose significant burdens on applicants, such as the costs of developing the proposal, the risks of failing to secure the bid, and more complicated financing arrangements (since the return on investment is not assured).[337] Thus, RPSs not only shift risk to investors, they also raise investors' transaction costs.[338]

While basic RPSs do not incentivize specific technologies, policy makers can add certain provisions – called multipliers and carve outs – to enable RPSs to promote particular technologies. Carve outs identify minimum levels of electricity to be produced from a particular type of source. These targets are "carved out" of the overall renewable energy percentage for the jurisdiction's electricity.[339] Conversely, multipliers allow the generation of electricity by particular energy sources to earn multiples of credits as compared to electricity produced by other

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328 For a more complete discussion of RPSs, *see* Anthony E. Chavez, *Using Renewable Portfolio Standards to Accelerate Development of Negative Emissions Technologies*, 43 WM. & MARY ENVTL. L. & POL'Y REV. 1 (2018).

329 Ryan Wiser, Galen Barbose, & Edward Holt, *Supporting Solar Power in Renewables Portfolio Standards: Experience from the United States*, 39 ENERGY POL'Y 3894, 3894 (2011).

330 Mormann, *Clean Energy Federalism*, *supra* note 132 at 1663.

331 *Id*.

332 Abolhosseini & Heshmati, *supra* note 161 at 881.

333 Jenny Heeter, Bethany Speer, & Mark B. Glick, INTERNATIONAL BEST PRACTICES FOR IMPLEMENTING AND DESIGNING RENEWABLE PORTFOLIO STANDARD (RPS) POLICIES 1 (2019).

334 Kang, *supra* note 127 at 28.

335 Mormann, *Clean Energy Federalism*, *supra* note 132 at 1631-32.

336 Couture & Cory, *supra* note 136 at 22.

337 Cory, Couture & Kreycik, *supra* note 126 at 9.

338 Mormann, *Clean Energy Federalism*, *supra* note 132 at 1664.

339 Environmental Protection Agency (EPA), ENERGY AND ENVIRONMENT GUIDE TO ACTION 5-10 (2015).

identified sources.[340] For instance, seven states use multipliers for solar, with multipliers of credits ranging from two to three times the standard one credit for each megawatt of generation by other renewable energy sources.[341] One benefit that both carve outs and multipliers share is that jurisdictions can apply these devices to several technologies at the same time, thereby supporting multiple undeveloped methods. Delaware, for instance, uses multipliers for fuel cells, solar, and offshore wind.[342] New Mexico, on the other hand, carves out minimum percentages of its RPS goals for solar, wind, and "other renewables."[343]

2. Differences between FITs and RPSs

At a fundamental level, the two systems differ in the focus of their approaches. FITs are price-based policies, whereas RPSs are quantity based.[344] Under FITs, regulators determine the price for power from particular sources, and the market determines the quantity to be installed.[345] Conversely, regulators under RPSs set the quantity of electricity to be sourced from designated technologies, and the market establishes the price.[346]

The different structure of these policies alters the allocation of risks. RPSs, which rely on competitive solicitations, shift more risk to investors.[347] By requiring particular quantities of renewable energy at whatever price providers can acquire it, RPSs incentivize cost reduction, while the risk of project acceptance and pricing falls on investors.[348] FITs facilitate the development of new technologies by requiring investors to assume only a minimal level of risk.[349] The guaranteed contract of FITs enables developers to avoid competitive solicitations. Also, they can secure financing for larger proportions of their projects, which helps lower the cost of financing.[350] Not only do FITs assure profitability, they also provide predictable returns.[351]

Because of the structural differences between FITs and RPSs, these policies tend to be most effective in incentivizing different types of investors and technologies. Quantity-based policies, such as RPSs, are better suited to more

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340 Greg Buckman, *The Effectiveness of Renewable Portfolio Standard Banding and Carve-Outs in Supporting High-Cost Types of Renewable Electricity*, 39 ENERGY POLICY 4105, 4105 (2011). Multipliers are also identified as banding. *Id*.

341 EPA, *supra* note 339 at 5-4-5-5.

342 Miriam Fischlein & Timothy M. Smith, *Revisiting Renewable Portfolio Standard Effectiveness: Policy Design and Outcome Specification Matter*, POLICY SCI (2013) 46:277–310, 290.

343 *Id*. at 287.

344 Kilinc-Ata, *supra* note 275 at 84.

345 Kwon, *Rent-Seeking*, *supra* note 183 at 677.

346 *Id*.

347 Cory, Couture, & Kreycik, *supra* note 126 at 9.

348 Kwon, *Rent-Seeking*, *supra* note 183 at 677.

349 Abolhosseini & Heshmati, *supra* note 161 at 884.

350 Cory, Couture & Kreycik, *supra* note 126 at 9.

351 Zhang, *Substitution Effect*, *supra* note 236 at 427.

mature technologies.[352] In addition, because of the uncertainty of return on investment with the competitive solicitation method used with RPSs, larger investors are better able to weather the costs and risks associated with starting projects.[353] RPSs also tend to favor projects with long-term targets (10-15 years) for profitability.[354] This also incentivizes more mature technologies, which are closer to competitiveness.[355] Because RPSs set quantity requirements and allow others to choose the technology with which to satisfy the mandate, they encourage lower-cost technologies,[356] which also tends to incentivize innovation to reduce costs.[357]

Conversely, guaranteed-price policies, such as FITs, tend to facilitate the development of technologies in their initial phases.[358] FITs also insulate covered technologies from competition with other technologies. Thus, they are especially effective at supporting new technologies that are not yet competitive.[359]

The risk shifting of these two policies also impacts regulators. The reduced risk encountered by investors with FITs does not disappear. Instead, FITs shift risk from investors to regulators.[360] In FITs systems, regulators must set the FITs rates. If regulators set the rates too high, the number of investors and projects will increase, but the overall policy costs will rise. If the rates are too low, market expansion will be constrained, since the most efficient projects will be viable.[361] The precision of these rates is essential because excess premiums would eventually burden ratepayers or taxpayers.[362]

Because of the limiting of investor risk by FITs, they have been the more popular policy.[363] In general, studies have found that FITs have more effectively promoted renewable energy development than any other policy.[364] Because of this difference, a study of 35 countries concluded that FITs mitigate investor risks and encourage up to four times the amount of renewable energy deployment as that incentivized by RPSs.[365]

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352 Francesco Nicolli & Francesco Vona, *Heterogeneous Policies*, *Heterogeneous Technologies: the Case of Renewable Energy*, ENERGY ECONOMICS 56 (2016) 190–204, 190.
353 IEA, *supra* note 61 at 132.
354 Kang, *supra* note 127 at 27.
355 IEA, *supra* note 61 at 132.
356 Ryan Wiser, Galen Barbose, & Edward Holt, *Supporting Solar Power in Renewables Portfolio Standards: Experience from the United States*, ENERGY POLICY 39 (2011) 3894–3905, 3896.
357 Nathaniel Horner, Iñes Azevedo & David Hounshell, *Effects of Government Incentives on Wind Innovation in the United States*, ENVIRON. RES. LETT. 8, 6 (2013).
358 Nicolli & Vona, *supra* note 352 at 190.
359 IEA, *supra* note 61 at 132. For this reason, as discussed more fully *infra* at Section IV.B, China has plans to utilize a mix of RPS and FIT policies - the former to incentivize the more established source of wind power and the latter to promote the less competitive technologies, such as solar photovoltaic. Zhang, *Substitution Effect*, *supra* note 236 at 433.
360 Mormann, *Clean Energy Federalism*, *supra* note 132 at 1660.
361 Alizamir, de Véricourt, & Sun, *supra* note 88 at 53.
362 UNEP, *Feed-in Tariffs*, *supra* note 124 at 7.
363 Schmalensee, *supra* note 137 at 60.
364 Barry, *supra* note 169.
365 Mormann, *Clean Energy Federalism*, *supra* note 132 at 1660. However, analysis suggests this may result more from a greater adoption of FITs policies than from a greater effectiveness of that approach. IEA, *supra* note 61 at 115.

Thus, each policy has its own strengths. RPSs support a managed growth of technologies and encourage innovation and cost reduction. FITs, however, have proven to be more robust promoters of new technologies.

E. Tax Credits and Cash Grants

While FITs and RPSs were the primary drivers of renewable energy deployment, other policies played significant roles. In the United States, particularly supportive were tax credits and cash grants.[366] Two types of tax credits have been used, one based on actual electricity generation and the other on the amount of investment in new technologies.

The United States enacted a production tax credit (PTC) that became a primary driver of wind energy.[367] Congress established the wind PTC in the Energy Policy Act of 1992. As originally enacted, the PTC provided a tax credit for the first ten years of operation of a wind turbine.[368] It provides a credit based upon the amount of annual electricity production from the turbine.[369] Thus, a primary benefit of the PTC is that it subsidizes the specific activity – electricity generation by wind turbines – Congress sought to encourage.[370]

Numerous studies have found that the PTC successfully encouraged wind power installations.[371] Researchers have found that the wind PTC has had a consistently positive and highly significant effect on wind technology deployment.[372] Furthermore, the PTC enhances the effectiveness of other supportive policies, most noticeably RPSs.[373]

One limitation inherent with the PTC is that, as a credit against taxes, it requires tax liability to provide value.[374] Because of the upfront costs involved with wind installations, however, developers do not typically produce profits (and the resulting tax liabilities) until after 10 years or more of operations.[375] Thus, to

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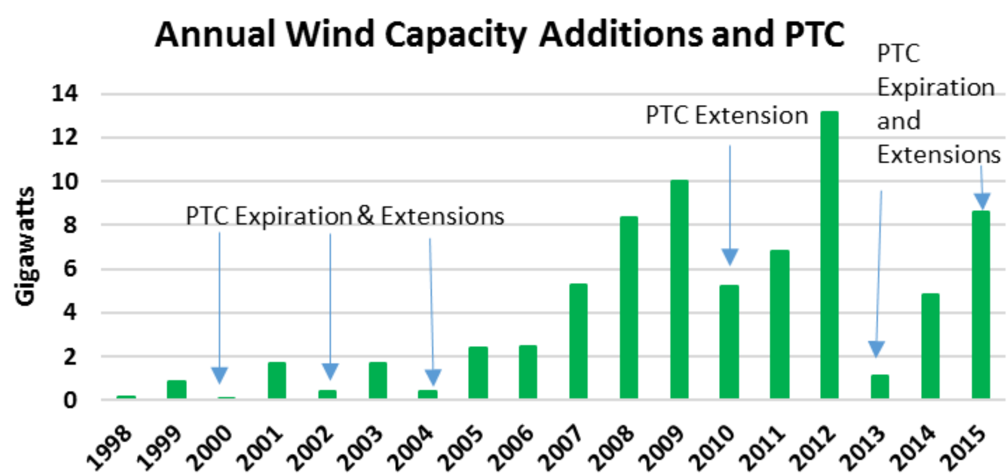
[366] Accelerated depreciation provisions also applied to renewable energy investments, but tax credits played a more significant role in renewable energy development. Felix Mormann, *Beyond Tax Credits: Smarter Tax Policy for a Cleaner, More Democratic Energy Future* (*Beyond Tax Credits*), 31 YALE J. ON REG. 303, 311 (2014).
[367] Ferrey, *supra* note 171 at 354.
[368] *Id*.
[369] Alexandra B. Klass, *Tax Benefits, Property Rights, and Mandates: Considering the Future of Government Support for Renewable Energy*, 20 J.Envtl. & Sustainability L. 19, 37 (2013). The Tax Code further requires that the electricity be sold to an unrelated party. Molly F. Sherlock, THE RENEWABLE ELECTRICITY PRODUCTION TAX CREDIT: IN BRIEF 1 (November 27, 2018).
[370] Victoria Chang, *Wind Energy Incentives in Texas*, 14 TEX. J. OIL GAS & ENERGY L. 189, 200 (2019).
[371] Sherlock, *supra* note 369 at 9.
[372] Gireesh Shrimali, Melissa Lynes, & Joe Indvik, *Wind Energy Deployment in the U.S.: An Empirical Analysis of the Role of Federal and State Policies*, RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 43 (2015) 796–806, 805.
[373] *Id*. at 806.
[374] Michelle D. Layser, *Improving Tax Incentives for Wind Energy Production: The Case for a Refundable Production Tax Credit*, 81 MO. L. REV. 453, 455 (2016).
[375] Mormann, *Beyond Tax Credits*, *supra* note 366 at 315.

benefit from the PTC, many developers needed to use tax equity financing to monetize their tax benefits sooner.[376] This process reduced the effective amount of financial support provided directly to the targeted activity, renewable energy production.[377]

Despite the PTC's success in growing the wind industry, uncertainty concerning its availability negatively impacted its effectiveness.[378] Congress repeatedly enacted the PTC for only a limited period of time and often let the credit expire before renewing it. Since the PTC's first enactment in 1992, Congress has needed to renew it eleven times.[379] On six of these occasions, Congress actually allowed the PTC to expire before extending it.[380] Figure 3 illustrates this history of the PTC's availability and its impact on wind power installations.

Figure 3[381]



Source: U.S. Department of Energy (DOE)- Electric Market and Policy Group.
PTC= Production tax credit.

The PTC's erratic availability reduced its effectiveness. The Department of Energy analyzed the effect of the starts and stops of the credit on the ability of

[376] Chang, *supra* note 370 at 197-98.

[377] Sherlock, *supra* note 369 at 10.

[378] Travis Roach, *The Effect of the Production Tax Credit on Wind Energy Production in Deregulated Electricity Markets*, ECONOMICS LETTERS 127 (2015) 86–88, 86.

[379] Ferrey, *supra* note 171 at 358 (identifying ten extensions as of 2018). In 2019, Congress extended the PTC an eleventh time to be available for projects commencing in 2020. John A. Eliason, David B. Weisblat, & Tori Roessler, *Production Tax Credit Extended for Renewable Projects Beginning Construction in 2020* (January 6, 2020), available at https://www.natlawreview.com/article/production-tax-credit-extended-renewable-projects-beginning-construction-2020.

[380] Ferrey, *supra* note 171 at 358.

[381] Isaac Orr, *Don't Believe the Wind Industry's Steel Tariff Talk, They Always Wanted More Subsidies* (October 16, 2019), available at https://www.americanexperiment.org/2019/10/dont-believe-the-wind-industrys-steel-tariff-talk-they-always-wanted-more-subsidies/.

developers to plan their projects. It used the date of congressional enactment and the expiration of the PTC to calculate a planning window for each PTC period.[382] The Department found that 14 such periods have arisen since 1992, and the average length of these periods was only 27.5 months.[383]

These regular expirations and extensions negatively impacted wind development.[384] They also engendered boom and bust cycles in the industry.[385] As illustrated by Figure 3, the cycles exhibit strong growth followed by dramatic slowdowns.[386] During the slowdowns, installations fell from 76% to as much as 93%.[387] These boom-and-bust cycles caused a number of problems within the wind industry itself and its supporting industries.[388] The drop in demand destabilized the industry's labor force and disrupted manufacturing processes and supply chains.[389] These disruptions impaired the industry's ability to take advantage of favorable developments, such as the tax credits' renewal or strong market conditions.[390] They also increased prices for goods and labor.[391]

These cycles do, however, demonstrate the impact of the PTC on the wind industry.[392] The effectivenss of the PTC is apparent by the dropoff in installations illustrated by Figure 3 when Congress allowed the PTC to expire. Consequently, Congress has amended the PTC to apply to additional technologies, including biomass, geothermal, landfill gas, municipal solid waste, qualified hydropower, and marine and hydrokinetic facilities.[393]

Another tax credit that Congress used to stimulate renewable energy was the investment tax credit (ITC). Congress first applied the ITC to renewable energy investments in the Energy Tax Act of 1978.[394] In contrast to the PTC, which rewards electricity generation,[395] the ITC mainly rewards the investment in equipment that enables that generation.[396] Thus, the ITC does not require – and, consequently, does not ensure – the actual generation of electricity by renewable

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382 Ryan Wiser & Mark Bollinger, U.S. DEP'T OF ENERGY, 2017 WIND TECHNOLOGIES MARKET REPORT 67 (2018).

383 *Id*. The author calculated more periods than extensions because, in some instances, the extensions provided that different investment periods would receive different credit amounts. For instance, the 2014 extension allowed a 100% credit for construction started before 2017, but only 80% for construction commenced before 2018. *Id*.

384 Klass, *supra* note 369 at 41-42.

385 Chang, *supra* note 370 at 196-97.

386 Union of Concerned Scientists, *Production Tax Credit for Renewable Energy* (Feb 9, 2015), available at https://www.ucsusa.org/resources/production-tax-credit-renewable-energy.

387 *Id*.

388 Blake Harrison, *Expanding the Renewable Energy Industry Through Tax Subsidies Using the Structure and Rationale of Traditional Energy Tax Subsidies*, 48 U. MICH. J. L. REFORM 845, 866 (2015).

389 *Id*.

390 Chang, *supra* note 370 at 197, n.58.

391 *Id*.

392 Mormann, *Beyond Tax Credits*, *supra* note 366 at 319.

393 *Id*. at 313. In 1992, the PTC included only closed-loop biomass along with wind. Sherlock, *supra* note 369 at i. By 2017, Congress had amended the PTC to cover the additional technologies. *Id*.

394 Mormann, *Beyond Tax Credits*, *supra* note 366 at 314.

395 Chang, supra note 370 at 200.

396 Mormann, *Beyond Tax Credits*, *supra* note 366 at 314.

sources. The ITC provides a credit of 30% of the investment in renewable energy equipment.[397]

Investors typically used the PTC for their investments in wind power, while the ITC has been the credit of choice for investment in solar power.[398] The distinction arose largely because of the differences in electricity generation by the two sources of power.[399] Historically, the per kilowatt capital cost of solar has been higher than that of wind. Thus, the ITC was more attractive for solar investments than those in wind.[400] Conversely, wind's higher generating capacity made the PTC more appealing to its investors.[401] In fact, the PTC could provide up to double the credit for wind developments that some solar projects could earn.[402]

Conclusions about the success of the ITC in incentivizing solar energy investments are mixed. Investment in solar power has undergone a significant increase since the passage of the ITC.[403] Nevertheless, a number of considerations call into question the ITC's role in causing this rise. For instance, the acceleration in solar installations does not coincide with favorable changes to the ITC.[404] Furthermore, solar energy has grown at similar levels worldwide.[405] Finally, analysts generally consider the PTC to yield more renewable energy per dollar of subsidy than has the ITC.[406]

Because of the necessity of having income to benefit from the tax credits, the government turned to a different mechanism during the Great Recession. The American Recovery and Reinvestment Act of 2009 (the Stimulus Bill) established section 1603 cash grants.[407] This provision enabled developers to choose to receive cash grants of up to 30% of their investments instead of receiving either the production or investment tax credits.[408] Congress enacted this provision in recognition of reduced investor demand for tax credits during the recession.[409]

Since cash grants provide financial benefits directly to investors, they have certain advantages over tax credits. Credits, as discussed before, require developers either to generate taxable income to benefit from the credit or to engage outside

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[397] Klass, *supra* note 369 at 38.
[398] Ferrey, *supra* note 171 at 354.
[399] *Id*. A renewable source's capacity factor refers to the actual electricity generated in a year divided by the maximum possible electicity that could have been produced. Simon P.Neill & M. Reza Hashemi, FUNDAMENTALS OF OCEAN RENEWABLE ENERGY: GENERATING ELECTRICITY FROM THE SEA 28 (2018). Capacity factors are important with renewable energy sources because their electricity generation is variable over multiple timescales. E. Ela, V. Diakov, E. Ibanez, and M. Heaney, IMPACTS OF VARIABILITY AND UNCERTAINTY IN SOLAR PHOTOVOLTAIC GENERATION AT MULTIPLE TIMESCALES 1 (2013).
[400] Ferrey, *supra* note 171 at 354-55.
[401] *Id*. at 355.
[402] *Id*. at 356.
[403] Brian Palumbo, *Looking in the Side-View Mirror: Assessing the Current and Future State of the Solar Energy Industry as It Reaches the Mainstream*, 41 COLUM. J. ENVTL. L. 183, 191 (2016).
[404] *Id*. at 201-02.
[405] *Id*. at 203.
[406] Sherlock, *supra* note 369 at 10.
[407] Mormann, *Beyond Tax Credits*, *supra* note 366 at 316.
[408] *Id*.
[409] *Id*.

investors to monetize their tax beneifts.[410] As a result, a significant portion of the subsidy goes to the outside investors and to efforts to identify and attract them.[411] Consequently, analysts have concluded that one dollar of direct cash has twice the benefit of one dollar of tax credit.[412] Not surprisingly, in the period after the passage of the Stimulus Bill, developers demonstrated a clear preference for cash grants over the tax credits.[413]

Another criterion upon which to evaluate these three mechanisms is their allocation of project risks. Since the PTC rewards production, project developers assume the risk of its nonperformance.[414] Conversely, the value of the ITC to the developer depends upon the amount of its investment, not its production.[415] Thus, the ITC does not assure electricity generation. Similarly, the government determines the amount of Section 1603 grants with reference to developer investments, not electricity generation.[416] Thus, the PTC better assures that the targeted benefit will actually be produced.

IV. USING RENEWABLE ENERGY POLICIES TO INCREASE CDR DIFFUSION

Diffusion theory and experience with renewable energy can help inform the crafting of policies to incentivize the development and deployment of CDR. The renewable energy experience suggests several principles that should guide these policies. Policies should provide for differentiation along a series of criteria, be stable until technologies are able to mature, but be able to adapt to new circumstances as technologies do reach later stages of diffusion. The renewable energy experience suggests that FITs are robust supporters of new technologies. However, they might work best operating in an RPS structure that assures steady growth while incentivizing least-cost technologies. At early stages of diffusion, additional policies that can subsidize new technologies, such as cash grants, have proven to be effective. As technologies become mature, subsidies need to be reduced and replaced with policies such as tenders that will contain costs.

A. Principles to Guide CDR Policies

Diffusion theory and the recent experiences with renewable energy development suggest several principles that should guide policies intended to promote CDR. A critical principle that must be incorporated into CDR policies is differentiation. To best promote CDR technologies, policy makers should develop

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[410] Sherlock, *supra* note 369 at 10.
[411] Mormann, *Beyond Tax Credits*, *supra* note 366 at 324.
[412] *Id*. at 322.
[413] *Id*. at 323.
[414] *Id*. at 322.
[415] *Id*.
[416] *Id*.

technology-specific, rather than technology-neutral, policies.[417] Policies must differentiate among technologies to take account of different stages of development, to recognize disparate geographic resources, and to assure development of a portfolio of different technologies. Tailoring policies to specifc technologies facilitates the development of less mature – and typically more expensive – technologies.[418] Experience with renewable energy illustrates that technologies develop at different paces,[419] necessitating policies targeted to their different locations on the S curve.[420] Similarly, CDR technologies currently are at different levels of development,[421] and, therefore, will benefit from the adoption of policies that allow for differentiation of policies.

Differentiation will have additional benefits. It will enable rates to recognize the geographic disparity of resources.[422] Differentiation also lowers the overall costs of the policies, since it facilitates reducing support for technologies further along on the diffusion curve.[423]

Tailoring is also important to avoid leaving technologies undeveloped. Essentially, those benefits that arise with technology maturity – economies of scale and learning by doing – become hindrances to the development of other technologies. Positive feedbacks and increasing returns to scale foster path dependency.[424] Path dependency locks in established technologies, not because they are superior, but because they are widely used.[425]

Once again, renewable energy provides examples of these concepts. For instance, Spain's potential for solar power is substantial.[426] Nevertheless, Spain's policies favored wind power and locked in that technology over others, including solar.[427] Another energy source that globally remains largely fallow is tidal power. Typical estimates calculate that tidal energy generation could exceed 100 GW worldwide.[428] Nevertheless, a lack of support for tidal power research has limited its development. Recently, Naval Group SA, a pioneer in tidal power, decided to shift its focus to offshore wind power because of limited support for tidal energy and competition from offshore wind.[429] Recent decisions by France to limit support for tidal projects and by the United Kingdom to require tidal projects to compete

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[417] IEA, *Deploying Renewables*, *supra* note 61 at 100.
[418] Del Rıo & Bleda, *supra* note 272 at 277.
[419] IEA, *Deploying Renewables*, *supra* note 61 at 95.
[420] *Id*. at 97.
[421] The Royal Society, GREENHOUSE GAS REMOVAL 79 (2018).
[422] Shrimali, Lynes, & Indvik, *supra* note 372 at 806.
[423] IEA, *Deploying Renewables*, *supra* note 61 at 100. Failure to reduce subsidies in recognition of the declining costs of mature technologies often results in windfall profits for them. del Rıo & Bleda, *supra* note 272 at 277.
[424] Sandén & Azar, *supra* note 188 at 1559.
[425] *Id*.
[426] Rao & Kishore, *supra* note 54 at 1073.
[427] *Id*.
[428] Lee Buchsbaum, *MeyGen Array Sets Global Records for Harnessing Tidal Power*, POWER (September 1, 2018), available at https://www.powermag.com/meygen-array-sets-global-records-for-harnessing-tidal-power/.
[429] Brian Parkin, *Tidal Power Shaken as Naval Group Drops Business for Wind Focus*, BLOOMBERG LAW ENVIRONMENT & ENERGY REPORT (July 27, 2018).

with offshore wind influenced Naval Group's decision.[430] The United Kingdom's focus on offshore wind indirectly impacted marine technologies by limiting their relative competitiveness.[431] To avoid such results, CDR technology policy needs to maintain support for still-developing technologies before their ultimate value has become apparent.[432] This will be especially important since analyses conclude that multiple CDR technologies should be developed to sequester the amount of carbon required.[433]

Experience with renewable energy also demonstrates that stability enhances the effectiveness of policies. The contrast between the results in Germany[434] with FITs and the uneven history of wind power installations in the United States[435] illustrates the importance of this factor. As demonstrated by the wind PTC, short-term extensions and occasional expirations of the credit injected uncertainty into the wind power market, leading to drops in installations greater than 90%.[436] Not only did this disrupt the clear upward trend in installations,[437] it also impacted the wind industry's employment, finances, and supply chain.[438] Conversely, Germany structured its FIT to provide decades-long certainty to investors.[439] Without doubt, this disparity helped wind power to achieve its fast growth in that country.[440]

Although CDR policies need to be stable, they must also be flexible. Diffusion theory tells us that technology deployment will follow a predictable – and changing – pattern.[441] In general, we can expect that CDR technologies will first undergo a period of innovation and early adoption.[442] This phase is characterized by limited diffusion as costs remain high.[443] During this period, supportive policies that lower the effective cost of installation will be especially helpful in promoting diffusion, since diffusion normally proceeds slowly.[444] As CDR technologies advance to the adoption stages, the costs of installations can overwhelm governments relying upon subsidies.[445] Thus, policies will need to adapt to contain their overall costs.[446] This will require regular reviews of market conditions to determine the optimal time to enact transitional policies.[447] Alternatively, they could rely upon predetermined levels, typically overall cost or

430 *Id*.
431 Nolden, *supra* note 79 at 5.
432 Lacerda & van den Bergh, *supra* note 103 at 8240.
433 James Mulligan, et al, CARBONSHOT: FEDERAL POLICY OPTIONS FOR CARBON REMOVAL IN THE UNITED STATES 9 (2020).
434 *See supra* at Section III.B.1.
435 *See supra* at Section III.E.
436 Union of Concerned Scientists, *supra* note 386.
437 *See* Figure 3, *supra*.
438 Harrison, *supra* note 388 at 866.
439 Suzuki, *supra* note 176.
440 Fowlie, *supra* note 180.
441 Davies & Diaz-Rainey, *supra* note 55 at 1229.
442 IEA, *Deploying Renewables*, *supra* note 61 at 97.
443 *Id*.
444 *Id*. at 101.
445 *Id*. at 102.
446 *Id*.
447 *Id*. at 103.

total installations, to implement changes in support.[448] Regardless of the particular mechanism, the policies will need to be able to adapt as the technologies mature.

B. A Policy Proposal to Support CDR Development and Deployment

Diffusion theory, the renewable energy experience, and the principles identified above can help guide the establishment of policies that can accelerate development and deployment of CDR technologies. At the initial stages, policies need to encourage investment, reduce costs, and provide stability. During the take-off stage, monitoring of changing conditions will be critical, with an expectation that policies will need either to evolve or be replaced to best fit new circumstances and to contain the overall costs of these policies. Finally, as markets begin to saturate, most policies can be removed altogether.

In light of the success demonstrated by FITs in promoting wind and solar power, FITs should be used as an initial policy to support technologies that capture and sequester carbon. Cost-based rates with premiums should be used since this method inherently differentiates among sources, which, among other benefits, supports portfolio diversification.[449] FITs have several characteristics that should contribute to the acceleration of CDR installations. First, their premium rates will ensure that investors will receive a favorable return, thereby encouraging investment.[450] Second, FITs incorporate long contract periods, which provide important stability for new technologies.[451] By setting different rates for different technologies, FITs also can promote multiple technologies at once.[452] Differentiated rates also can recognize geographic differences in technologies' effectiveness and tailor rates accordingly,[453] thereby controlling overall costs.[454]

FITs, however, have not proven to be perfect. Although FITs usually fostered substantial renewable energy growth,[455] the costs of this growth led many FITs countries to abandon or severely restrict these policies as technologies matured.[456] Both in Europe and Asia nations have been shifting away from FITs to market-based methods.[457] In other instances, they failed to stimulate the anticipated growth in renewable energy.[458] Thus, changes will be required to ensure that CDR installations achieve their targeted level while avoiding burdensome costs. To ensure that installations continue even when FITs are reduced or eliminated, FITs should be used in conjunction with RPSs.

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[448] Mormann, *Clean Energy Federalism*, *supra* note 132 at 1662, n.231.
[449] UNEP, *Feed-in Tariffs*, *supra* note 124 at 41.
[450] *Id*. at 40. To ensure profitability, a CDR FIT should thus commence with a cost-based rate. *Id*. at 38.
[451] Resch, *supra* note 140.
[452] UNEP, *Feed-in Tariffs*, *supra* note 124 at 41.
[453] Lacerda & van den Bergh, *supra* note 103 at 8246.
[454] IEA, *Deploying Renewables*, *supra* note 61 at 100.
[455] UNEP, *Feed-in Tariffs*, *supra* note 124 at 5.
[456] *Supra* at Section III.C.1.
[457] REN21, *supra* note 123 at 122.
[458] Kang, *supra* note 127 at 11.

Typically, jurisdictions have approached the two policies as mutually exclusive alternatives.[459] However, in recent years analysts have begun to suggest that FITs and RPSs can be used jointly, either as separate but parallel measures or with FITs serving to promote certain technologies within a broader RPS structure.[460] Using the two policies jointly can be more effective since this approach is able to combine the policies' most effective provisions.[461] Furthermore, analysts have concluded that use of both policies increase their effectiveness.[462] Importantly, both policies can support tailoring for specific technologies.[463]

The RPS structure can readily incorporate FITs policies.[464] RPSs can act as a framework with which other policies can be integrated to achieve the RPSs' requirements.[465] With their tradable certificates, RPSs create markets for technologies; FITs can encourage investment in the technologies intended to populate these markets[466] and help achieve the RPS quotas.[467] Specifically, FITs and RPSs can interact in several ways. First, FITs can provide a more certain means to award contracts as compared to the competitive solicitation process typically used in RPS jurisdictions.[468] Second, jurisdictions can use FITs to award contracts when no competitive solicitations are pending.[469] Third, FITs can work in conjunction with RPSs, providing a means to promote targeted technologies.[470] In place of or in addition to carve outs and multipliers, RPSs can utilize FITs to encourage investment into technologies jurisdictions favor or seek to develop. FITs can be especially helpful when RPSs are first implemented as a means to accelerate investment in undeveloped technologies.[471] Finally, because they lower barriers to

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[459] Mormann, *Clean Energy Federalism*, *supra* note 132 at 1628.

[460] Cory, Couture & Kreycik, *supra* note 126 at 11.

[461] Kang, *supra* note 127 at 75.

[462] Fugui Dong, et al, *Study on China's Renewable Energy Policy Reform and Improved Design of Renewable Portfolio Standard*, ENERGIES 2 (2019), 12, 2147.

[463] FITs can differentiate tariffs by technology type. Couture & Cory, *supra* note 136 at 18. RPSs, on the other hand, can target specific technologies by utilizing carve outs (EPA, *supra* note339 at 5-10) or multipliers. Buckman, *supra* note 340 at 4105

[464] While a traditional RPS requires utilities to comply with their mandates, EPA, *supra* note 339 at 5-11, here the RPS mandate should be applied effectively as a carbon offset for industrites with high CO_2 emissions. California, for instance, will allow carbon capture and sequestration as an offset to companies with high-carbon intensity fuels under its Low Carbon Fuel Standard. California Air Resources Board, ACCOUNTING AND PERMANENCE PROTOCOL FOR CARBON CAPTURE AND GEOLOGIC SEQUESTRATION UNDER LOW CARBON FUEL STANDARD 7 (undated).

[465] Zhao Xin-gang, et al, *The Policy Effects of Feed-In Tariff and Renewable Portfolio Standard: A Case Study of China's Waste Incineration Power Industry*, WASTE MANAGEMENT 68 (2017) 711–723, 711-12.

[466] Mormann, *Clean Energy Federalism*, *supra* note 132 at 1658.

[467] Couture & Cory, *supra* note 136 at 22.

[468] *Id*.

[469] *Id*.

[470] *Id*.

[471] Xin-gang, et al, *supra* note 465 at 721.

market participation, FITs enable governments to encourage investment by small investors.[472]

Using the RPS framework provides several crucial benefits. RPSs can serve as baseline policies that assure smooth and continuous growth.[473] RPSs can also be helpful after technologies have progressed along the diffusion curve.[474] They can enable jurisdictions to avoid the financial burden of additional installations with FITs subsidies while assuring continued installations of the technology.[475] As noted previously, South Korea replaced its FIT with an RPS, and renewable energy installations then increased three fold over their rate under the South Korean FIT.[476] Furthermore, with their utilization of competitive markets to encourage investment in lowest-cost technologies, RPSs can help control the burden of FITs subsidies.[477]

One country that is combining FITs with RPSs is China. It is utilizing a portfolio approach to renewable energy development, combining RPS policies with FITs and other policies.[478] As noted previously, China enacted its RPS in response to problems with its FIT.[479] Specifically, the FIT incentivized the development of solar PV in resource-rich portions of the country, but low development also characterizes these regions.[480] Becaue of a lack of long-distance transmission lines, this PV development – and its attendant costs – were wasted.[481] China then imposed an RPS to control PV waste, to balance special deployment, and to contain policy cost.[482] Thus, it turned to RPSs to assure controlled and directed growth while using FITs to incentivize that growth.

Finally, to enhance the effectiveness of these policies, governments should incorporate cash grants and tax credits. Because many CDR technologies are still nascent,[483] we can anticipate that most CDR developers will have minimal taxable income for several years. Cash grants will usually be most effective in these circumstances since they will assure that a larger proportion of the government's support will stay with the developers.[484] Still, the production tax credits can be valuable tools to incentivize more mature technologies that are already able to

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[472] Abolhosseini & Heshmati, supra note 161 at 879. Conversely, experience has demonstrated that another means to acquire renewable energy generation, tenders, raise barriers to participation by small investors. Fell, *supra* note 114 at 11.
[473] Herman K. Trabish, *Why Mandates Still Matter in the Age of Cheap Renewables* (Why Mandates Still Matter), UTILITY DIVE (January 3, 2018), available at https://www.utilitydive.com/news/why-mandates-still-matter-in-the-age-of-cheap-renewables/513797/.
[474] Abolhosseini & Heshmati, *supra* note 161 at 884.
[475] Xin-gang, et al, *supra* note 465 at 721 (suggesting that FITs subsidies can be reduced or canceled as investments increase, thereby controlling costs. Policy makers can then increase RPS quotas to assure continued installations).
[476] Lo, *supra* note 126.
[477] Mormann, *Clean Energy Federalism*, *supra* note 132 at 1628.
[478] Dong, *supra* note 462 at 20.
[479] *Supra* at III.B.3.
[480] Ye, Rodrigues, & Lin, *supra* note 221 at 497.
[481] *Id*.
[482] *Id*.
[483] NAS, *supra* note 11 at 40.
[484] Mormann, *Beyond Tax Credits*, *supra* note 366 at 324.

produce the desired product, carbon sequestration.[485] The final mix of subsidies may be less important than the fact that subsidies are available. From the perspective of investors, analysts have found that the extent of price support is at least as important as the type of instrument that provides it.[486]

As CDR technologies mature and enter the take-off phase, subsidies – FITs, grants, and tax credits – will need to be reduced to avoid excessively burdensome costs. Accordingly, administrators will need to monitor installations and overall costs. As both rise, they will need to degress the FIT rates and prepare to transition from subsidies to tenders.[487] Experience demonstrates that auctions can work well independently or in conjunction with broader structures, such as FITs or RPSs. Tenders can, for instance, serve several different functions within FITs. Jurisdictions can use tenders to procure larger projects,[488] leaving FITs to support smaller installations.[489] Alternatively, governments can use tenders as a device to determine the appropriate price level for the FITs subsidies.[490]

The German experience illustrates another role for tenders. First, it used FITs to assure predictability of renewable energy investments. After the technologies matured, it then replaced its FITs with auctions, thereby not only controlling its subsidy costs but also lowering the price of energy.[491] Tenders also have worked successfully within the RPS structure. New York[492] and California[493]

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[485] Chang, *supra* note 370 at 200.

[486] Valentina Dinica, *Support Systems for the Diffusion of Renewable Energy Technologies—n Investor Perspective*, ENERGY POLICY 34 (2006) 461–480, 463.

[487] Another policy similar to FITs that might better control overall costs is Advance Market Commitments (AMCs). AMCs arose as a means to incentivize the production of vaccines for developing countries. Global Health Technologies Coalition (GHTC), EXPLORING THE ROLE OF THE US GOVERNMENT IN A FUTURE ADVANCE MARKET COMMITMENT 1 (undated). They consist of a pool of funds available to producers of specified products, in this case, vaccines. AMCs guarantee a market at a specific price. *Id*. Unlike FITs, however, they do not guarantee that all available products will be purchased. Center for Global Development, *What is an Advance Market Commitment?*, (February 18, 2005), available at https://www.cgdev.org/blog/what-advance-market-commitment. Thus, they still enable purchasers to select the best product for their purposes, thereby incentivizing manufactureres to improve their products. *Id*. AMCs increase revenues and reduce their volatility. Vivid Economics, *supra* note 269 at 18. By providing certainty regarding demand, AMCs stimulate investment. *Id*. at 16. AMCs are most effective at supporting existing technologies or incremental R&D improvements. *Id*. at ii. They are especially appropriate for products that benefit society, but may not necessarily be profitable. GHTC, *supra* note 487 at 3. Experience has demonstrated that AMCs accelerated the production and distribution of targeted vaccines, though other factors may also have had an effect. Christopher M. Snyder, Wills Begor, & Ernst R. Berndt, *Economic Perspectives on the Advance Market Commitment,* HEALTH AFFAIRS 30, No. 9 (August 2011), 1508-1517, 1514-15.

[488] Couture, et al, *supra* note 295 at 5 (recognizing that, because of their administrative and transaction costs, tenders favor larger investors and larger projects).

[489] Fell, *supra* note 114 at 17-18 (concluding that for small projects jurisdictions should abandon the use of tenders and instead rely upon FITs).

[490] Schenuit, et al, *supra* note 220 at 40.

[491] Reed Landberg, *Germany Seeks to Become First to Auction Energy Efficiency Deals*, BNA ENVIRONMENT & ENERGY REPORT (Oct. 01, 2018).

[492] IRENA, *supra* note 294 at 38.

[493] California Public Utilities Commission, RPS Procurement Programs, last visited July 25, 2019, available at https://www.cpuc.ca.gov/RPS_Procurement_Programs/.

provide examples of states that use tenders to secure renewable energy projects to satisfy RPS requirements. Furthermore, combining tenders with RPSs will overcome one of the common objections to tenders – underrealization of installation targets.[494] The rising minimum requirements under RPSs will assure that installations will continue to achieve higher targets.[495]

V. CONCLUSION

Virtually all projections conclude that keeping warming under 2°C will require the use of CDR technologies, and in substantial quantities. Although many such technologies are available, few are ready to be deployed at scale, and many still require significant development. Diffusion theory helps demonstrate how this deployment may unfold, but, even more importantly, how policies may accelerate this process while containing its costs. The recent experience of renewable energy deployment points to several policies that may accelerate the diffusion of CDR technologies. The RPS structure can set rising targets for deployment and incentivize continual innovation of mature technologies. FITs provide conditions favorable to encouraging investment and deployment of still-developing technologies. Importantly, however, FIT premiums must be reduced or eliminated as the technologies pass through the take-off stage of the S curve. At this point, RPS minimums and tenders should be able to ensure that diffusion continues and does so at the lowest costs possible.

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[494] Kreiss, Ehrhart, & Haufe, *supra* note 302 at 512.
[495] EPA, *supra* note 339 at 5-10.