Empowering New Energy: How Protective Spaces Enable a Renewable Energy Transition

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Garrett Hanrahan

Spring 2020

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

“*Change is the law of life and those who look only to the past or present are certain to miss the future.*”

—John F. Kennedy

Introduction

Reports form the International Panel on Climate Control detail that a path to zero carbon output needs to happen in the near future to avoid a 3 to 4-degree Celsius increase, the current path the earth is on (Harvey, 2018). A 1.5 to 2-degree Celsius increase is inevitable, yet there will still be massive consequences for that best-case estimation (IPCC, 2019). Each half of a degree increase in global average temperature results in significant amplification of environmental consequences such as flooding, deadly heat waves, agricultural losses, habitat losses, human displacement and much more (Plumer, 2018). There is a desperate necessity to begin deep decarbonization, meaning reducing global carbon emissions entirely. Renewable energy (RE) provides one way to reduce carbon emissions, yet it makes up a very small part of the national energy mix: only 15% of domestic energy production (EIA, 2019). Unfortunately, global emissions are still rising, for there was 1.7% growth in emissions in 2018, meaning the earth has not even stopped increasing the yearly emissions due to the drawback of REs (Roberts, 2019). At a moment when our planet needs to be reducing carbon output as soon as possible, we continue to burn fossil fuels as our primary form of energy at an alarming rate, creating more devastating consequences for the near future.

Battery technologies are an emerging innovation and a requirement for the future of renewable energies. REs struggle to compete due to issues of reliability, making them less desirable than existing carbon-emitting sources. Battery storage fixes the problem of reliability for REs, but the current state of battery development and costs results in much higher energy prices. Adrian Smith details the obstacles facing a promising innovation that is looking to undergo a large-scale sociotechnical transition when saying:

> Socio-technical regime theory argues alignments and mutual interdependencies across multiple socio-technical dimensions also generate processes of lock-in and path-dependency. Path-breaking sustainable innovations are at a structural disadvantage within these contexts, because they are too demanding in terms of their socio-technical implications for the regime. (Smith, 2009, 12)

Battery technologies fall victim to these same obstacles in their diffusion. The prices for battery storage are much higher, and the current structure of the grid is not supportive of industrial battery storage. This yields a fairly difficult path for the sociotechnical transition to batteries.

The paper focuses on strategic sociotechnical transitions, evaluating literature and cases regarding governments conducting transitions management, defined as "long-term visions, which function as a framework for formulating short-term objectives and evaluating existing policy" (Rotmans, 2001, 23). Specifically, the research will focus on one form of transitions management: the formation of protective spaces, as defined by Adrian Smith. Protective spaces allow new innovations to develop and mature, without the pressure of competing with existing technologies, so they may be best supported for a large-scale transition and diffusion. This paper will explore the facets of protective spaces as they relate to the development of disruptive technologies, and it will apply transitions frameworks form both Frank Geels and Adrian Smith to provide a better understanding of pathways to a fully renewable energy future.

Battery Technologies as the Obstructed Key to Supporting a More Renewable Grid

Phasing out carbon-based energy production is the necessary future of the energy realm. There is a requirement for a large-scale sociotechnical transition to achieve this goal. Renewable energies are picking up traction, but they are still not quite as feasible as fossil fuel-based power for two reasons: cost and reliability. The imbalance of solar and wind energy generation compared to energy demand puts a lot of stress on fossil fuel-firing plants, such as gas and coal, to deliver peak energy generation (Waters, 2019). Figures 1 and 2 below detail the ways in which solar energy strengthens a reliance upon fossil fuel-based energy.

Figure 1: A general hourly grid energy demand curve (blue) and solar generation curve (orange/yellow) (Groves, 2019).

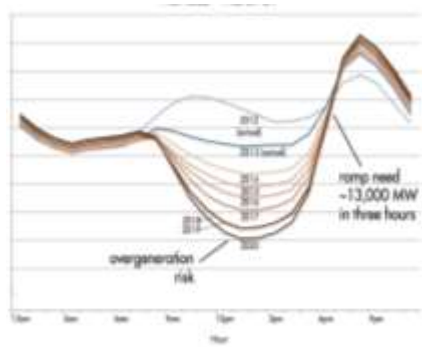

Figure 2: The remaining grid energy demand curve after solar energy generation. (Roberts, 2018).

Figure 1 demonstrates the solar energy generation (yellow and red), and the energy demand curve (blue) over the course of a day. Figure 2 depicts net load or, more simply put, the remaining energy to be dispatched after solar serves some of the demand. This creates a large ramp to meet the evening peak in the net load, and only fossil fuels can fill that gap. Fossils fuels can only deliver that need because they can easily generate energy when it is needed on short notice, unlike RE.

To address issues of reliability, battery technology allows for excess energy to be stored when it is not needed (around midday) and discharged to fulfill the evening demand peak. This storing and strategic discharging method fixes the unreliable power production, eliminating the necessity of fossil fuel-based energy sources (Jones-Albertus, 2018). As shown in figure 3 below, the energy stored (and discharged), makes the net load much more manageable.

Figure 4: Solar energy generation with Battery Storage

A full RE transition is reliant upon battery storage to make RE sources more reliable. Unfortunately, battery storage comes with a large cost, nearly 3 to 4 times that of standard fossil fuel-based prices (Lazard, 2018). RE alone struggles to compete with the existing fossil fuel-based technologies due to unreliability, and the battery technology paired with RE struggle to compete on the grounds of cost. These drawbacks hold carbon-neutral energy sources to only a minor portion of energy generation profile, leaving room for more carbon to be emitted into the atmosphere.

A full sociotechnical transition to REs paired with battery storage requires a systematic approach to enabling and assisting this transition. This begs the questions: when and how? This paper only addresses the question of "how" a sociotechnical transition to battery storage could take place. There are a few frameworks that begin to evaluate sociotechnical transitions, and the frameworks presented in this section will demonstrate flaws in previous analysis. The flaws or shortcomings of these frameworks will be addressed later on in the paper.

Jan Rotmans defines a framework for implementing large scale sociotechnical transitions called Transitions Management, the goal of which is to assist and operate a transition given a certain objective and existing structure. He clarifies the concept when explaining that transitions management requires "long-term thinking (at least 25 years) as a framework for shaping short-term policy." He also assigned the responsibilities within his framework when saying that "government can and should assume a leading role in transitions management" (Rotmans, 2001, 26). This was some of the first work evaluating the structure of a sociotechnical transition, but this framework itself lacks the specific details of how one specifically manages a large-scale transition.

Another framework that builds off of Rotman's is the Technology Innovation Systems approach. The TIS approach is best defined as "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" (Carlsson & Stankiewicz, 1991, 95). The TIS framework details a solid structure to nurturing an innovation, but the success of the innovation is only regarded as a result of its performance. In other words, it is "inward looking, and does not pay much attention to the system's environment" (Markard and Truffer, 2008, p.

610). TIS analysis struggles to explain a large-scale diffusion of a disruptive innovation because it involves more interactions than TIS considers (Smith & Raven, 2019, 1029). These frameworks for understanding transitions have glaring flaws, and the next section explains more suitable frameworks for analysis.

Frank Geels identifies a specific form of transitions management when explaining that "the creation of 'protective spaces' is a useful and important means of encouraging emerging innovations because they shield these innovations from the pressures imposed by the existing systems and give them time to mature" (Geels, 2018, 26). These "protective spaces" are formed and supported by government action, as Rotmans suggests earlier. For example, German solar, wind and nuclear energy were able to flourish after the 2000 Renewable Energy Act, which established a 20-year long feed in tariffs. In other words, the government promised to purchase energy form any carbon-neutral sources at higher prices than carbon-emitting sources, and this allowed RE's to develop and improve before truly competing with fossil-fuel based energy sources. This policy wholly supported renewable energy innovation in Germany, and it eventually led to Germany earning the title of "the first renewable energy economy" (Burgermeister, 2009). This case demonstrates that a protective space approach as a form of government-induced "exogenous pressure" has vastly changed the future of REs in Germany, and it aided the acceleration of deep decarbonization in a country that leads the world at the moment. These protective spaces will be the means of transitions management that will be analyzed later on in this research.

Part II: Combining of Multi-level Perspective and Protective Spaces Yields a Strong Framework for Analysis

The first analytical framework used to understand the case studies of protective spaces is Frank Geels' Multi-level Perspective. In this framework, Geels defines three levels of sociotechnical transitions: "niches (the locus for radical innovations), socio-technical regimes (the locus of established practices and associated rules that stabilize existing systems), and an exogenous socio-technical landscape" (Geels, 2012, 10). The first level describes the direct support to the innovation itself, and how well it creates niches for the innovation. The second level describes the existing structure of the stabilized system in place. Geels' diction demonstrates the solid foothold through practices, infrastructure, relationships, etc. that the existing system has in place to maintain itself. The third, and final level details the overarching landscape such as the politics, and social trends surrounding the innovation. He argues that a successful, large-scale transition occurs at the convergence of these three levels.

This will be one of the frameworks used to evaluate the cases of protective spaces presented later. Geels notes that these three levels of understanding a transition all differ in size and complexity. The first two levels are clashing against each other, while the third, larger level dictates and influences both of them. He further explains that niche innovations build "internal momentum," changes in the landscape level pressure the regime, and the regime falls apart to make way for the niche innovation. The convergence of these three levels best supports a sociotechnical system, and it provides a "window of opportunity" for the innovation (Geels, 2012, 4). I plan to use this framework to evaluate protective spaces as a form of supporting sociotechnical systems. In looking through cases of the applications of protective spaces, I expect to see one glaring difference. They, by design, automatically fulfill the 1st level because they are designed to promote the innovation itself. I think protective spaces will differ in the way that they affect change in the 2nd level, the existing regime. This same thought is reiterated by Geels:

> The regime level is of primary interest, because transitions are defined as shifts from one regime to another. The niche and landscape levels can be seen as 'derived concepts,' because they are defined in relation to the regime, namely as practices or technologies that deviate substantially from the existing regime, and as external environment that influences interactions between niche and regime"

This framework has its shortcomings as a suitable means to analyze case studies, for it fails to accurately define the 1st and 3rd levels of the MLP. The exogenous landscape is naturally hard to define or understand, given its large scope and size. A second analytical framework, defined by Adrian Smith et al, works to dissect the innovation and its surrounding environment directly. His framework defines protective spaces as a concept designed to shield, nurture, and empower these innovations. He further explains his framework when saying:

> Shielding provides temporary relief for niche innovations against selection pressures from the incumbent regime; nurturing focuses on learning, articulating expectations and networking between actors; while empowering focuses on activities that make niche innovations competitive vis-à-vis existing dominant regimes."

Smith claims that shielding entails specific actions to initially protect the new innovation or system from pressures of competing with existing the existing system. Nurturing entails practices that continue the development of the innovation. These levels of a protective space provide additional information on the first level of Geels' MLP. Smith defines two forms of empowerment: "fit and conform vs stretch and transform." Fit and conform suggests that this new innovation is able to compete with the other structures once the shielding is removed. The essence "stretch and transform" empowerment is captured by its title; it "aims *not* at fully removing shielding, but rather institutionalizing parts of it; it seeks to change mainstream selection by incorporating sustainability values" (Verhees et al, 2013, 286). A protective space that falls under the "stretch and transform," category impacts and reshapes actors at all three levels. A protective space that institutionalizes new selection criteria to the benefit of the innovation is both pressuring the existing regimes and altering the exogeneous landscape. Initially it appears that Smith's framework only applies to the niche level of the MLP, yet empowerment impacts more levels of the MLP. In this sense, this form of empowerment is shaping more than just the niche level of Geel's MLP, and empowerment actually plays roles in all three levels of the MLP.

The combination of these two frameworks yields a more comprehensive and analytical framework, which is detailed the figure 4 below. These two frameworks together provide a more detailed form of analysis to break down and evaluate previous uses of protective spaces on renewable energies. Specifically, they categorize and break down a socio-technical transitions so different levels and aspects of the protective space can be evaluated simultaneously. The combined frameworks are displayed in figure 5 below. They address the issues shown in Transitions Management and TIS frameworks, which lacks specific breakdowns and the complexity of interactions in a disruptive innovation. These frameworks complement each other in a way that allows them to evaluate cases much more effectively. Geels provides a high level understanding, while Smith dissects the specific aspects of a protective space, making case studiers more easily evaluated.

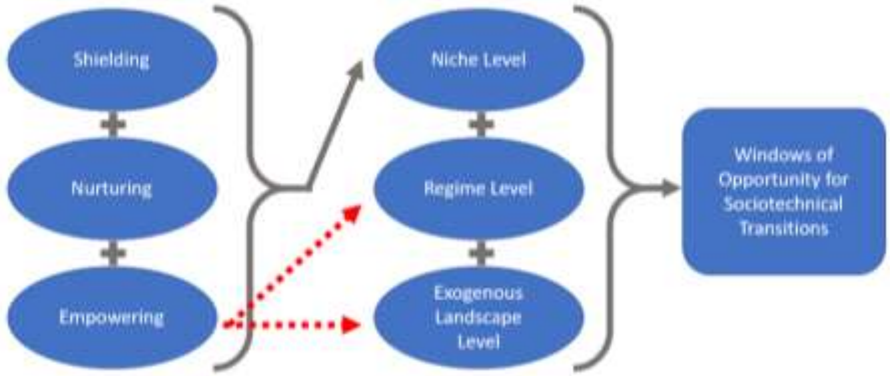

Figure 4: Integrated Framework from Frank Geels and Adrian Smith

In the same way that I expect the results to be dictated by 2nd level of Geel's scope, I also expect the results to be dictated by this difference in terms of empowerment. A protective space that does not "stretch and transform" and rather fits the system into the existing regime will not lead to a successful large-scale sociotechnical transition. The exogenous landscape will not undergo a full transition, and the innovation would only work alongside the existing structure in a less significant way.

Part III: Case Studies Demonstrate Nurturing as a Deciding Factor in Sociotechnical Transitions.

Florian Kern provides the first case to be evaluated in this framework. He demonstrates the initial slow uptake of offshore wind in the United Kingdom, and then its takeoff through the use of protective spaces. There was a strong push for REs to meet the ambitious goals of climate and RE targets, and a fair amount of the land space had inherent issues (eyesores, noise, etc).

The first concrete shield came from a policy devoted towards Nuclear Energy, which was subsequently applied to OSW. There was also a large influx in public funding for OSW after the early 2000's that actively shielded OSW from competing with existing structures. The government provided nurturing of these protective spaces when the UK's Technological Innovation Needs Assessment predicted installations scenarios ranging from 20 to 100 GW by the year 2050 along with GDP contributions of 7-35 billion pounds. This led to "credible expectations" of the OSW departments. By setting these expectations, they gave space for the research spaces to produce, and attracted investments.

Finally, the government empowered OSW largely through the Electricity Market Reform. "This represented a radical overhaul of the electricity markets rules in order to empower investment in low carbon generation by introducing long-term feed in tariffs" (642). The government allowed for special procedures for OSW farms that gave them precedence over other zoning issues such as protected conservation areas, whereas other developments were not allowed to build there. These are all examples of "stretch and transform empowerment" that institutionalized advantages for OSW.

This example demonstrates how the government, industry, and research spaces fulfilled all three of Smiths protective spaces by nurturing, shielding and empowering. There was certainly support in the niche level by the shielding, nurturing, etc and in the exogenous level by government and policy support. All of these levels of support led to a promising sociotechnical transition, wherein the UK leads all other countries in OSW installation.

Bram Verhees details the second case: the Dutch PV industry, which was facing an uphill battle from the start. He described a structure of "unfavorable policy" for solar energy (287), as the government did not view solar energy as a viable domestic energy source. The solar industry was described as being "invisible" to the Dutch government until 2009.

The Dutch Solar industry was only able to develop by employing fit and conform empowerment along with minimal, yet strategic, shielding and nurturing. The biggest PV advocates pushed for shielding to avoid the "premature death" of their innovation. This shielding came through the mobilization of funds for semiconductor research, which loosely applied to the general PV movement. Also, advocates targeted small niche areas, which were not connected to the grid, and they used this to continue manufacturing solar panels even though it was not used by most of the Netherlands. The solar development was nurtured through strong actor networks, specifically between research institutions and industry. Key PV advocates help influential positions as university professors, and they had direct contact and influence in the Ministry of Economic Affairs.

This case demonstrates how a protective space was able to work, even though the exogeneous landscape provided weak support, as shown by the lack of real political support. In this sense the PV transition was not empowered in the same way that OSW in the UK was, yet the Netherlands is still able to maintain a sociotechnical transition. Strong actor networks between academics and industry protected the innovation despite political backing.

H. E. Normann details the third case: offshore wind and the use of protective spaces. This final case is unique because it demonstrates a case that failed in a renewable sociotechnical transition. He lays the background of the situation when saying "an electricity sector dominated by hydropower and a reliance on cost efficient policy measures has provided few opportunities for immature energy technologies over the past two decades" (Norman, 2015, 181), yet significant developments in the exogeneous landscape, as global warming became evident as an imposing problem to both the public and government. Alsaug Haga, a RE enthusiast, was appointed as the Minister of Petroleum and Energy in 2007. Haga and others' work led to a negotiation of the Climate Agreement in parliament in 2007. From these meetings, eight eco-friendly research spaces were created, 2 of them specifically for offshore wind energy. These research spaces received large support and contributions from the energy industry, specifically some oil and gas companies.

Despite all of the efforts of Haga and others, it became clear that OSW in Norway was not going to achieve a full sociotechnical transition. Although there has been government support for R&D of offshore wind and significant private investment, only 2.3 MW of capacity has been installed offshore in Norway, compared to the over 8,000 MW of OSW capacity in the UK. There was significant investment in OSW demonstration projects by Statoil, Shell, and other oil and natural gas companies, and these companies were receiving public funding and assistance from research groups. Yet there was a gap in the networks required for nurturing of this innovation, as shown when Normann says a "lack of collective action and a single proposal to the authorities shows that the offshore wind industry suffered from weak networks" (Normann, 2015, 185). This draws a strong contrast to the case of both the UK and Netherlands, who had strong research, industry and government actor-networks. These firms needed learning not only to demonstrate technology, but to also foster further learning processes and build support for a technology. Eventually, this window for sociotechnical opportunity closed with a new minister of Petroleum put in after 4 years of Alsaug Haga, and the disconnected actor networks failed to capitalize on an opportunity for a sociotechnical transition due to a lack of proper nurturing (Normann, 2015, 189).

To connect all of these case studies, the diagram below demonstrates how each case compared to the others.

	Geels 1st Level (niche)					
	Shielding	Nurturing	Empower (fit and conform)	Empower (stretch and transform)	Geels 2nd Level (regime)	Geels 3rd Level (landscape)
UK OSW	✓	✓	✓	✓	X	✓
Nether. PV	✓	✓	✓	X	X	X
Norway OSW	✓	X	✓	✓	X	✓

Figure 5: Results of Case Studies as they relate to the frameworks of analysis

These case studies all lacked a specific mention of Geels' second level: the pressuring of existing regimes. These Governments are actively willing to support and aid the new technologies, but they have not made significant pushes to edge out the incumbent systems in place. This shows a largely untapped strategy for socio-technical transitions.

The policies that appeared most easily successful were those that institutionalized shielding for the innovations, through the stretch and transform means of empowerment. As shown through the case of British OSW, adding in permanent advantages for renewables supported and attracted more investment in the industry. These are more obvious results from the case studies that confirm and adhere to both Smith and Geels' frameworks.

The cases also demonstrate the complexity and unpredictability of achieving a sociotechnical transition. It is clear that these windows of opportunity do not guarantee a successful transition. This result also shows how a sociotechnical system can survive with fairly weak empowerment. The case of Dutch PB shows that the most significant factor in capitalizing on windows of opportunities are instances of actor networks that work to nurture the innovation. It showed a necessity for a general level of preparation through shielding and nurturing, so that once the exogeneous landscape, as explained by Geels, shifts to support the industry, then the innovation, actor networks, and general system around it must be ready to scale up manufacturing and diffusion. Otherwise, that window of opportunity is missed, as shown in the case of Nowegian OSW. Despite strong exogeneous landscape support, the landscape can change and the window effectively closes.

Conclusion

These case studies all revealed a lack of government role in pressuring the existing structures, which has often occurred in other markets such as tobacco. Pressuring of the incumbent regimes could take form in many ways such as a carbon tax, as it relates to industrial battery technology. So far, efforts in the renewable energy transition have not fulfilled Geels' MLP, as there has been no pressure put on the existing regimes. There is space to argue that empowering the renewable sector in a stretch and transform manner has begun to put pressure on the existing fossil fuel fired regime because that sector does not experience the same level of institutionalized advantages. Still, this remains an un-used form of transitions management that could accelerate battery technology uptake and diffusion.

These case studies gave insight into the significance of nurturing, and its powerful role in supporting disruptive innovations. The cases showed that windows of opportunity can close and open based on exogenous landscapes (public and political support), yet proper shielding and nurturing is required to maintain the technology until a moment of opportunity arises. The exogenous landscape is largely beyond the control of actor-networks who are supporting the innovation. These actors need to ensure the innovation survives, so it is ready to succeed when the opportunity presents itself.

Finally, the cases studies demonstrate that financial empowerment alone is a meaningless form of empowerment. Megan Mazzucato explains that a sociotechnical transition "is not just funding innovation alone, but also envisioning the opportunity space, engaging in the most risky and uncertain early research, and overseeing the commercialization process" (Mazzucato, 2011, 48). Investment in technological development for a potentially disruptive innovation means nothing without proper shielding and nurturing in place to strengthen the innovation, and those innovations will not succeed without the proper support system around it.

This research provides a deeper understanding for governments, industries and research space as they support sociotechnical transitions. As the US and other governments attempt to develop and install industrial battery storage, proper shielding and nurturing is a requirement to strengthen, prepare and continue the survival of the innovation as the window of opportunity approaches. As shown earlier, that window can only open for a short time, and the success of this innovation relies on proper nurturing to capitalize on the opportunity.

References:

Commented [1]: Some of my edits here might be wrong, I'd double check with the slides Neeley has posted

Burgermeister, J. (2009, April 3). Germany: The world's first major renewable energy economy. *Renewable Energy World*. Retrieved from: https://www.renewableenergyworld.com/2009/04/03/germany-the-worlds-first-major-renewable-energy-economy/#gref

Carlsson, B & Stankiewicz C. (1991). On the nature, function, and composition of technological systems. *Journal of Evolutionary Economics* 1. 93-118.

CRP. (2019, September 11). Energy storage continues to grow and get more affordable. *The Climate Reality Project*. Retrieved from: https://www.climaterealityproject.org/blog/energy-storage-continues-grow-and-get-more-affordable

Divya, K, & Ostergaard, J. (2009). Battery energy storage technology for power systems—An overview. *Electric Power Systems Research, 73*(4), 511-520. https://doi.org/10.1016/j.epsr.2008.09.017

EDF. (2018, January). Clean energy is building a new American workforce. *The Environmental Defense Fund.* Retrieved from: https://www.edf.org/energy/clean-energy-jobs

Energy Information Agency (2019). What is US's electricity generation by energy source? Retrieved from: https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

Fatima, Y. A. Raven, R. & Arora, S. (2015, October). Scripts in transition: Protective spaces of Indonesian biofuel villages. *Technological Forecasting and Social Change 99.* p1-13. Retrieved from: https://doi.org/10.1016/j.techfore.2015.06.021

Geels, F, Shwanen, T, Sorrell, S, Benjamin, K, & Sovacool, B. (2018, June). Reducing energy demand through low carbon innovation: A sociotechnical transitions perspective and thirteen research debates. *Energy Research & Social Science, 40*, 23-25. https://doi.org/10.1016/j.erss.2017.11.003

Geels, F, Sovacool, B, Shwanen, T, & Sorrell, S. (2017, September 22). Sociotechnical transitions for deep decarbonization. *Science, 357* (6357), 1243-1244. https://science.sciencemag.org/content/sci/357/6357/1242.full.pdf

Harvey, C. (2018, June 19). World has only 20 years to meet ambitious 1.5-degree C warming threshold. *Scientific American.* Retrieved from https://www.scientificamerican.com/article/world-has-only-20-years-to-meet-ambitious-1-5-degree-c-warming-threshold/

Hess, J. (2018, June). Energy democracy and social movements: A mutli-coalition perspective on the politics of sustainability transitions. *Energy Research & Social Science, 40,* 177-289.

IPCC. (October, 2018). Global warming of 1.5 C. *International Panel on Climate Change.* Retrieved from: https://www.ipcc.ch/reports/

Jones-Albertus, B. (2017, October 12). Confronting the duck curve: How to address over-generation of solar energy. Office of Energy Efficiency and Renewable Energy. Retrieved from: https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

Kern, F. (2014, June). From laggard to leader: Explaining offshore wind developments in the UK. *Energy Policy 69* p 635-646. Retrieved from: https://doi.org/10.1016/j.enpol.2014.02.031

Lazard. (2019). Lazard's levelized cost of storage analysis—Version 4.0. *Lazard.* Retrieved from: lazard.com/media/450774/lazards-levelized-cost-of-storage-version-40-vfinal.pdf

Mclaren, J. (2019). Identifying potential markets for Behind-the-meter battery energy storage: A survey of U.S. demand charges. *National Renewable Energy Laboratory.* Retrieved from: https://www.nrel.gov

Plumer, B, & Popvich, N. (2018, October 7) Why half a degree of global warming is a big deal. *The New York Times.* Retrieved from https://www.nytimes.com/interactive/2018/10/07/climate/ipcc-report-half-degree.html

Roberts, D. (2017, October 27). The key to tackling climate change: Electrify everything. *Vox.* Retrieved from: https://www.vox.com/2016/9/19/12938086/electrify-everything

Roberts, D. (2018, October 11). Utilities have a problem: The public wants 100% renewable energy, and quick. *Vox.* Retrieved from: https://www.vox.com/energy-and-environment/2018/9/14/17853884/utilities-renewable-energy-100-percent-public-opinion

Roberts, D. (2019, June 26). The global transition to clean energy, explained in 12 charts. *Vox*. Retrieved from: https://www.vox.com/energy-and-environment/2019/6/18/18681591/renewable-energy-china-solar-pv-jobs

Rotmans, J, & Kemp, R. (2001, February). More evolution than revolution: Transition management in public policy. *Foresight 3*(1), 15-31.

Sioshansi, F. (2018, October 5). Electricity's future: Mostly behind the meter distributed generation. *Energy Post.* Retrieved from: https://energypost.eu/electricitys-future-behind-the-meter-distributed-generation/

Smith, A. (2014, January). Spaces for sustainable innovation: Solar photovoltaics and electricity in the UK. *Technological Forecasting and Social Change 81* pg 115-130. Retrieved from: https://doi.org/10.1016/j.techfore.2013.02.001

Smith, A. & Raven, R. (June, 2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy 41*(6). 1025-1035

Thompson, A. (2019, July 1). Utility-scale energy storage will enable renewable grid. *Scientific American* Retrieved from: https://www.scientificamerican.com/article/utility-scale-energy-storage-will-enable-a-renewable-grid/

Verhees,B. (2013, March). The development of solar PV in the Netherlands: A case of survival in unfriendly contexts. *Renewable and Sustainable Energy Reviews 19* pg 275-289. Retrieved from: https://doi.org/10.1016/j.rser.2012.11.011

Waters, C. (2018, May 9). This "duck curve" is solar energy's greatest challenge. *Vox.* Retrieved form: https://www.vox.com/2018/5/9/17336330/duck-curve-solar-energy-supply-demand-problem-caiso-n