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Article

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Research paper

Blind spots in energy transition policy: Case studies from Germany and USA

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ABSTRACT

Energy transitions aim at economic prosperity through ‘green-collar’ job-creation, greater energy ‘independence’, and/or reduced emissions. These objectives imply creating policy-supported national renewable technology industries, ideally reducing clean energy costs to a point where support becomes unnecessary. Two dimensions of competition arise: renewables competing with incumbent technologies, and local renewable technology industries competing with others globally. Policy can, sometimes, overlook the evolution of such competitive pressures due to three blind-spots. Policy support may: create demand that outstrips the domestic industry’s capacity to expand – generating jobs overseas; underestimate the pace at which costs of a new technology are falling and become inadvertently over-generous; underestimate innovation potential in incumbent technologies, which necessitates longer-than-anticipated support for the renewable technology or, at worst, cease support before the new technology is sustainably cost-competitive.

These blind-spots suggest that policymakers may incorporate more realistic representations of foreseeable changes in the competitive dynamics of industry and trade into transition planning. Ultimately, clean energy penetration intends to reduce absolute fossil-fuel consumption, which may trigger a more competitive response from affected suppliers than seen so far. This will be experienced as reductions in production costs due to demand clearing down the supply cost-curve and the supply cost-curve itself moving downwards.

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1. Introduction

Whether through feed-in-tariffs (FIT), renewable certificates, tax credits, or otherwise (Cheng and Yi, 2017), there are three broad goals that drive governments to require a shift in reliance on fossil fuels to renewables: achieving greater energy security and/or independence, mitigating negative environmental impacts, and/or developing manufacturing and service sectors that would contribute to economic prosperity and create employment opportunities.

Each of these goals poses challenges on its own. If two or more goals are to be achieved simultaneously, the task becomes even more complicated because these transition goals may compete with each other. During the past 25 years particularly, many countries around the world have set targets that are to be met in a specified timeframe. Australia for example committed that at least 20% of its electricity needs will be met from renewable energy by 2020 (Moosavian et al., 2013), while Germany intends to reach a renewables-based share of gross final energy consumption

of 18% by 2020 (BSW, 2014). Saudi Arabia plans to install 9.5 of renewable energy by 2023 (Gamal et al., 2017). As can be seen, renewable energy targets can be represented as a percentage of electricity generation, a percentage of energy consumption, an absolute capacity or generation target, or a combination of these.

Without a doubt, transitioning to new energy norms is not something that occurs rapidly or easily. In fact, and as a general rule of thumb, history tells us that transitions require prolonged periods of time to evolve (Fouquet and Pearson, 2012). The prevailing economic, social, and political conditions, among others, will impact the design of policy to varying degrees (Grubler, 2012). The displacement of conventional electricity generation requires the development of a new technology that is competitive with the incumbent. Financial policy instruments aim to incentivize investments in renewables and subsequently improve the economics of renewable generation. Energy transition policy has also typically been seen as offering encouragement to the development of the local renewable technology service and manufacturing sectors. In support of such economic growth objectives, direct and indirect incentives are utilized to establish globally-competitive national supply chains (Lund, 2009; Solomon and Krishna, 2011). Considering local and global competitive dynamics is, therefore,

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Nomenclature

CC	Combined Cycle
CCGT	Combined Cycle Gas Turbine
EEG	German Renewable Energy Sources Act
EPAct	Energy Policy Act
FIT	Feed-in-Tariff
GDP	Gross Domestic Product
GW	Giga Watt
LCOE	Levelized Cost of Energy
MOF	Ministry of Finance
MOST	Ministry of Science and Technology
PTC	Production Tax Credit
PV	Photovoltaics
RPS	Renewable Portfolio Standard

central to transition policy design. Locally, ambitious penetration targets mean, at least partially, winning the competition for power generation. Globally, the race among nations to establish market leadership can have significant implications on national industry formation and expansion.

But the technological and industrial aspects of transitions are certainly not the only aspects that need to be carefully considered by policymakers. The demand for energy, in all of its forms, is a fundamental factor that drives prices, decisions, and prosperity of energy industries. Within the past two decades, while the percentage share of incumbent fuels and technologies has somewhat shrunk through time, their absolute consumption level has not (Solomon and Krishna, 2011). Here, there is an interesting demand story that is worth telling.

Policies supporting renewables and/or penalizing conventional energy sources are intended, ultimately, to decrease the demand for conventional energy. Given that renewables are relatively 'young' compared to conventional technologies, it is reasonable to assume that there is room for technological advancement and cost reductions in renewables. If the latter occurs, and is indeed occurring as shown by falling solar and wind technology costs, the demand for conventional energy would down, making conventional energy more attractive cost-wise (Blazquez et al., 2018). Similarly, a (Blazquez et al., 2018)s demand for renewable technologies increases, their selling prices would increase making them less attractive. The above assumes that both types of technologies are substitutes, and ignores the fact that conventional energy sources are actually subsidized in many places around the world.

Global energy demand, however, has not been stagnant – it has been steadily increasing with an exception during the financial crisis of 2008. Global oil consumption for example has grown more than 14 million barrels per day above 2003's level of over 80 million barrels per day according to the 2015 British Petroleum Statistical Review. The same also applies for Natural gas, where a steady increase in consumption has been witnessed until the end of 2015. Even coal consumption has been steadily increasing up until 2014, but with a slight drop of 1.8% only in 2015 compared to 2014 levels. This overall rise in global demand has drawn increasingly expensive resources and caused markets to clear at higher prices than would have been the case in an environment of stagnant demand. This growth in demand for conventional fossil fuels, which is not necessarily always given its due weight, can thus be viewed as having contributed to the competitiveness of renewables.

The above discussion clearly indicates that it is not easy to design or implement energy transition policies. In fact, we only discussed two aspects, while other aspects including environmental and social acceptance are beyond the scope of this paper.

Notwithstanding these challenges, it is possible to take a discerning look at previous transitions that have already occurred to extract insights and avoid unintended consequences that were not seen except with hindsight.

In this paper, we share with the interested community some recommendations based on recent transitions that stem from Germany and the United States. Explicitly, three blind-spots are presented from the experiences of these two countries which are certainly considered leaders in the renewable energy circle. The objective of the paper is to share with the energy policy circle some examples and observations in a concise manner. The intention of this paper is not to formulate new theories or present innovative analytical methodologies. Rather, the paper essentially summarizes past events that took place in the form of lessons-learned. Renewable energy is steadily growing worldwide and the case studies presented in the paper can be of value for countries who have just embarked or will embark on the renewable energy journey.

2. Methodology and case description

2.1. Methodology

As mentioned in the introduction, the aim of this paper is to take a closer look at previous transitions in the interest of extracting insights that would be beneficial in the future. Given the nature of the topic and the objective of the study, it was deemed that a qualitative research approach would be most suitable. A qualitative paradigm fits the thesis of the paper as we seek to explore, explain, and understand (Bryman, 2017) some phenomena that were associated with energy transition quests. Further, the findings are intended to be provided in the form of a narrative (Sovacool et al., 2018) rather than numerical or statistical form.

The choice of a qualitative methodology serves a long-term objective of this study, which is developing hypotheses that could be tested at a later stage using quantitative techniques. All quantitative methods must be founded on qualitative grounds, and this study will better inform potential subsequent model development in the form of parameter introduction or linkages of different variables and/or equations. More on this point will be discussed later in the paper.

Within the qualitative research domain, we will implement a mix of narrative and case-study methods (O'Sullivan and Howden-Chapman, 2017; Sovacool et al., 2018), where the sequence of events will be closely scrutinized. With the aid of these methods we intend to answer two important research questions: (1) what were some unintended consequences that have surfaced as a result of previous transitions, and (2) how could these consequences be avoided in the future?

Policymakers typically recognize the likelihood of improving performance of renewable technologies in the future and how the costs of manufacturing the components may change over time with the aid of learning curves (Reichelstein and Yorston, 2013) and scale economies (Yu et al., 2011). Both factors are particularly important if a government intends to adopt push-policies. But, as explained above, energy transitions are too complex to be described or characterized by a few theories or equations, and it is reasonable to assume that deviations from what was expected may (and indeed, will) occur. In fact, entirely unexpected developments may arise and require consideration in policy formation. The catastrophe that occurred in Fukushima in 2011, for example, is one that frustrated several plans and warranted full reevaluation of (renewable) energy policies and targets. Such developments are not ones that could be anticipated.

The effectiveness of transition policy can, by and large, be measured by assessing improvements in relative competitiveness

along two dimensions: (1) cost competitiveness of the new technology versus the incumbent fuel and technology combination within a country; and (2) cost competitiveness of domestic manufacturing and service industries versus global suppliers. Intentionally or not, policy and incentive design seem, for the most part, to have overlooked the evolution of new competitive pressures in these two dimensions. This paper will identify and discuss three resulting blind-spots:

- Policy support may create demand that outstrips the local supply chains' ability to expand – thus generating the high tech “green jobs” overseas. An illustration is provided by Germany's solar photovoltaic (PV) industry being unable to match the surge in demand precipitated by aggressive policy support. This forced German customers to resort to imports, mostly from China.
- Policy support may underestimate the pace of innovation in a new technology and remain inadvertently over-generous, precipitating an uptake frenzy that has to be calmed by removing or reducing the incentive.
- Policy support may underestimate or not expect the pace of innovation in the incumbent fuel and technology combination, resulting in making the cost reductions achieved in the renewable technology less pronounced. It is reasonable to assume that if conventional technologies see that the costs of renewables going down, then conventional technology companies may respond by reducing their own prices or investing more in research and development. If the conventionals retaliate to the competition, this would result in necessitating more support for renewables for longer than anticipated or withdrawal of support before the new technology is sustainably cost-competitive. For example, wind energy in the United States demonstrates how technological advancements in the field of hydraulic fracturing, which reduced natural gas prices, dwarfed cost reductions that were achieved in the wind turbine industry even before a decline in demand for natural gas was witnessed.

These examples suggest that policymakers and relevant stakeholders may benefit from considering possible scenarios that may evolve in the competitive dynamics of industry and trade alongside market equilibria into their energy transition planning. Previous transitions serve as a good candidate to learn from. Note that whether these changes occur as a deliberate competitive response or evolve naturally is immaterial. Insurance, entering into hedging agreements, and crafting contracts in a manner that allows revisions and amendments to be made to the contract on a regular basis are possible options to mitigate risk and deal with changing market landscape. Such considerations that account for potential changes in the competitive landscape are important in the longer term if the penetration of clean energy capacity begins to reduce the market for fossil fuels in absolute terms. This will elicit a more aggressive competitive response from suppliers of those commodities and in related value chains than has been seen to date (Stenzel and Frenzel, 2008).

2.2. Blind-spot 1: Demand outstripping local industry capacity – Germany's PV FIT program

The Germany PV journey continues to be among the most researched case studies in the field of renewable energy transitions (Beermann and Tews, 2017). The intention here is not to elaborate on Germany's progress toward meeting its policy objectives. Rather, we make observations related to the effectiveness of policy instruments in establishing a competitive solar PV manufacturing sector given global dynamics.

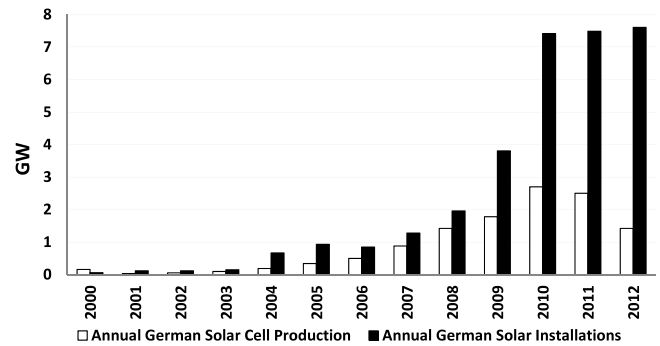


Fig. 1. The annual solar cell production and total solar installations for Germany for the years 2000 through 2012 (Fronde et al., 2010; Hoppmann et al., 2014; IEA, 2013).

The driving force in promoting renewable energy in Germany has been the Renewable Energy Sources Act introduced in 2000, which, based on the German equivalent, is abbreviated as EEG. The FIT program had already been in effect since the early 1990s. EEG set targets for renewable energy, aspiring for other positive impacts including stimulating the economy (Fronde et al., 2010), increasing employment opportunities (Fronde et al., 2008), and boosting innovative capabilities (Pegels and Lütkenhorst, 2014). Given the generous incentive support, it is not surprising to see that Germany has lead the world in cumulative installations of solar PV capacity with approximately 35.7 GW added between 2000 and 2013 (BSW, 2014). As of 2016, Germany stood on a formidable 41 GW of solar PV installations.

The lucrative incentives maintained PV demand at high and stable levels, which was initially somewhat matched by growth in local solar cell production capacity (Fig. 1). However, in 2004 annual PV system installations began growing at a much faster rate than the production capacity. In fact, the annual installations in 2010 and 2011 for example were nearly thrice the local production capacity. Clearly, the national industry was unable to cater for this explosion in demand or grow at a matching pace and Germany began relying increasingly on imports. Because of the increased reliance on imports, many consider the objectives that the EEG intended to achieve were not actually achieved effectively (Pegels and Lütkenhorst, 2014).

Meanwhile, and since the 1990s, China began to provide strong support to export-oriented industries. By the mid-2000s, the share of exports of the gross domestic product (GDP) grew to 36% compared to only 9% in 1980 (Liu and Goldstein, 2013). This focus on exports was also coupled with the desire of the Chinese government to support the development of industries that are both capital- and technology-intensive, and at the same time considered vital for national security and economic infrastructure (Liu and Goldstein, 2013; Mattlin, 2009). The solar PV industry, including silicon purification, wafer manufacturing, and cell production, has easily satisfied these conditions for receiving support.

Multiple policy initiatives have equipped China to become a world leader in solar manufacturing. For example, the ministry of finance (MOF) granted exemption from value added tax and import tax for manufacturing equipment purchase. The ministry of science and technology (MOST), on the other hand, established several national programs to support high-tech research and development (Fan and Watanabe, 2006). Even city governments played an important role by refunding 50% of the loan interests for investments beyond ¥500 million in solar PV manufacturing equipment and other technologies (Huo and Zhang, 2012). Policy instruments rapidly motivated a surge in solar cell production capacity. In 2011, for example, while Germany produced nearly 2.5 GW of solar

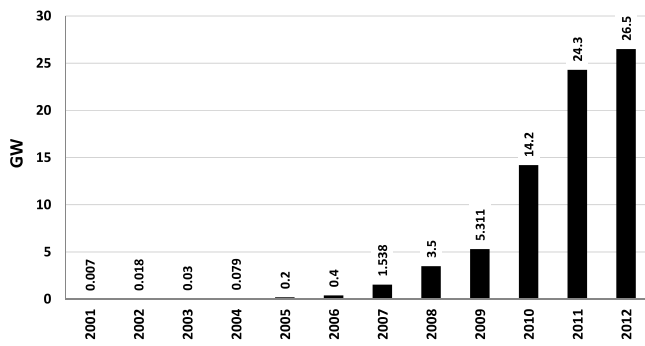


Fig. 2. Annual solar cell production for China, including Taiwan for the years 2001 through 2012 (Fang et al., 2014; Insitute, 2014).

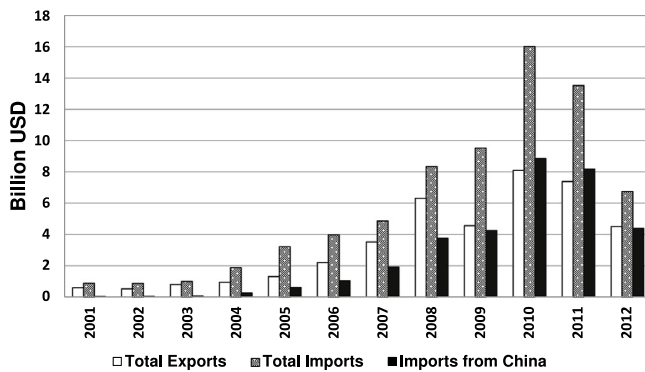


Fig. 3. Germany's total exports, total imports, and imports specifically from China of photosensitive semiconductor device, photovoltaic cells & light emit diodes, i.e. harmonized source code: 854 140.

Source: KAPSARC based on UN Comtrade Database.

cells, China produced nearly 10 times as much. China was able to boost its production from almost 1.5 GW in 2007 to a formidable 26.5 GW by 2012 (Fig. 2). Policy support for the PV industry in China, coupled with policy support for solar PV installations in many countries worldwide, has made China the major player in the global PV market (Weick and Jain, 2014).

Although the PV manufacturing sector in Germany grew significantly (Geels et al., 2017), it was unable to grow as fast as local demand or beat China on cost. The latter would hold true even if the Germans have not exported any of their PV production. While the solar industry has prospered and created a significant job market within Germany, the scale of imports was remarkable (around 50% in some years). Critics argued that this large magnitude of imports came at the expense of local jobs. In other words, the concern was directed towards the scale of imports, not the import activity itself, as trade is known to be healthy to economies if well managed. Germany remained a net importer of solar cells for over a decade. Fig. 3 shows how net imports increased drastically in 2009–2011, with a growing share of these imports sourced from China.

The Chinese industry has been serving solar PV markets in Germany as well as other countries. Simultaneously, dissatisfaction grew in Germany around a wasted opportunity to create jobs and expand the PV manufacturing sector. The competitive position market of German manufacturers was further hurt by China, with its ability to produce modules cheaper given unprecedented levels of scale economies (Goodrich et al., 2013). While Germany has succeeded in establishing global leadership in solar PV demand, China has been able to establish leadership in module supply. As eloquently described previously by Grau et al. (2012), it is important to distinguish between the policy support that promotes

deployment and installation of solar PV, and policy support that promotes establishing an industrial PV sector.

When the FIT program was initiated in the early 1990s, followed by the EEG in 2000, the potential for intensifying global competitive pressures was not clear. It was difficult, and perhaps even impossible, to anticipate that China would evolve into the PV manufacturing colossus it has become. The resultant pressure of manufacturers in China and elsewhere on Germany's PV industry was probably not incorporated into policymaking, and more detailed assessment of the barriers, drivers, and opportunities surrounding the local and global PV industry would have been beneficial in the policymaking process (Von Geibler et al., 2018).

To continue the discussion about this specific blind-spot, and for the sake of comprehensiveness, it is important to note that this policy blind-spot will not always occur whenever a country provides support to a technology. For example, although China benefited from the German EEG in the solar PV segment, it did not benefit as much from policies that promoted wind energy deployment in many countries around the world. Two arguments can provide explanation to this observation.

First, global manufacturing leaders in the wind industry were mostly non-Chinese companies, i.e. GE, Vestas, and Siemens. These firms had the potential to increase production to meet a surge in demand without necessarily resorting to other suppliers. In the PV industry however, which is closely tied to the integrated circuits industry as both require purified silicon to create the final product (Kasap and Capper, 2017), Chinese companies were, and still are, global leaders and were able to increase production at a competitive price rather quickly compared to other rivals.

Second, there is a difference in the technology characteristics between wind and solar. A 2 MW solar farm, for example, would require twice as much modules as a 1 MW solar farm. The same is not true for wind technology: the rotor diameter (which is determined by the blade length), the hub height, and turbine do not need to double in length/size if the capacity of the wind turbine is to double (Enevoldsen et al., 2018). In other words, wind technology scales better compared to solar PV. Hence, the increase in wind turbine demand was being met without the need to rely on other suppliers/countries given the more relaxed constraints. There could have been also some shipping challenges as the size of blades and hubs is relatively large and would require special handling arrangements that would add to the price.

Based on this scrutiny, policymakers and industrial policy experts can assess if this blind-spot would occur by carefully considering the details and characteristics of the technology, current supply chain capacity, industry potential to expand, magnitude of support, and shipping logistics. These factors, collectively, provide a better picture as to whether this blind-spot would occur or not.

2.3. Blind-spot 2: Reasonable incentives becoming profligate – changes in clean energy technology costs

We continue capitalizing on the German PV experience, since a foundation was built in the previous section, to illustrate how changes in the costs of the renewable technology being supported can result in transforming an existing reasonable policy to an over-generous one.

Although the EEG came into effect in 2000, it was not until 2004 that the annual installations began to tickle the 1 GW mark as shown in Fig. 1. The total installations that occurred between 2004 and 2008 were orders of magnitude higher than those that occurred between 2000 and 2004. Electricity consumers have borne the brunt of this explosion in installations, where consumers had to carry a heavy 2 billion euros on their shoulders in 2008, which is a 600% increase compared to the 2004 level (Hoppmann et al., 2014).

The situation was further exacerbated as the costs of PV module manufacturing decreased significantly 2008–2009. This cost fall was not expected. Not surprisingly, this cost reduction resulted in an amendment to the EEG in 2009 to mainly limit any additional costs on consumers and to curtail manufacturers' windfall profits. Most notably, the static FIT decrease of 5% was replaced by a dynamic reduction mechanism. But the story does not end there.

By the end of 2009, PV system costs witnessed yet another reduction due to a large drop in silicon spot prices and a global supply–demand imbalance (Bazilian et al., 2013) (silicon is the material that is used to manufacture solar cells). The rapid expansion of the solar PV market in China was chiefly responsible for this imbalance (Yu et al., 2016). Once again, the EEG was amended and a reduction in remuneration on all system sizes was enforced in August 2010. Other reductions and amendments have also taken place within this timeframe causing some to describe this policymaking behavior as compulsive (Hoppmann et al., 2014). Such an observation is an important one, and can serve as a valuable experience to many countries intending to deploy solar PV. Detailed comparison studies benefiting from the German experience and capitalizing on the lessons-learned have been conducted as in Mundo-hernández et al. (2014) for example.

The German FIT initially guaranteed a price for PV-generated power that is fixed for 20 years. Although the initial FIT amount could have been relatively, and justifiably, high in the initial phases of PV deployment given the high technology costs and to attract investors, unexpected technological advancements and polysilicon market dynamics have obligated the German government to revisit previous policies.

2.4. Blind-spot 3: Competitive advances in the incumbent – 20 years after the US wind production tax credit (PTC)

Numerous federal and state mandatory and non-mandatory policy measures have been put in place to promote a rapid penetration of wind and other renewable energy sources over the past two decades in the United States. Chief among these tools is the federal production tax credit (PTC), which would reward the production and sale of electricity from qualified facilities during the first 10 fiscal years of operation. The PTC was originally introduced by the Energy Policy Act (EPAct) of 1992. Since its first expiration in 1999, the PTC was renewed eight times through 2013 (Table 1). Also during the past two decades, 29 states and the District of Columbia have enacted renewable portfolio standards (RPS) policy mandating specific percentages of energy requirements be supplied by renewable energy within specific timeframes (Table 1).

While state RPS has been a key determinant of new facility location, PTC levels and schedules dictated the timing and amount of investments (Fig. 4). Between 1993 and 2013, developers added about 60 GW of wind capacity across the United States. However, as suggested by trends in 2012 and 2013, the financial viability of wind plants still appears to hinge upon the availability of federal incentives.

Although the support mechanism of the RPS was the same in essence across states, the deployment levels that were arrived at each state were different. This variation cannot be explained solely by wind resource patterns or US state policies, and indicates the importance local and central governance (Fischlein et al., 2014). The level of deployment that each state arrived at was a result of different technical, political, and economic circumstances (Fischlein et al., 2010). It is also noted that the RPS policy, which has been adopted in a number of countries around the world, is considered among the effective mechanisms to promote wind energy as indicated in Saidur et al. (2010). Hence, it is not surprising to see that the US adopted this mechanism and did indeed achieve high penetration rates in wind technology.

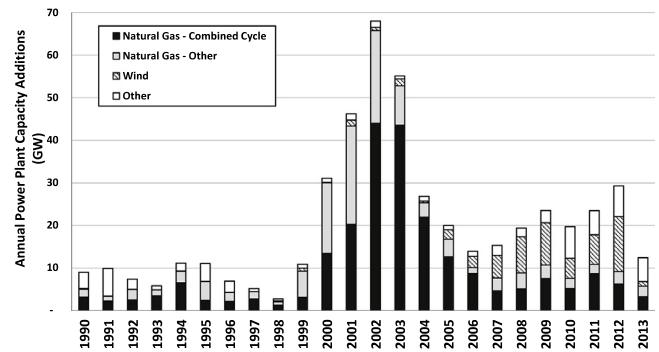


Fig. 4. Historical power plant additions in the US since 1990 have been dominated by natural gas-fired facilities, with wind taking a larger share recently. Wind additions typically diminished at PTC expiration.

Source: EIA data.

Following innovation and development efforts in the 1980s, new efficient General Electric (GE) “F” class natural gas turbine technology was commercialized in the early 1990s. In addition to its relatively high efficiency, this new technology enjoyed short construction cycles and low capital costs. These advantages, together with restructuring the power markets, favorable natural gas price, and supply expectations, fueled a gas-fired construction boom between the late 1990s and mid-2000s. About four fifths of power plant installations since the initial implementation of the PTC were natural-gas fired. Efficient combined cycle (CC) technologies represented two thirds of this amount as shown in Fig. 4.

During the same time frame, electricity demand growth slowed down significantly from an average annual growth rate of about 4% in the 1970s and 1980s to approximately 2% in the 1990s and 1% in the 2000s. This has been driven by a combination of three major recessions, the ensuing restructuring away from manufacturing, and improved efficiencies across the economy. The combination of the power plant building boom and depressed load growth resulted in a capacity glut, and intensified competition among generating technologies beyond expectations when the PTC was conceived.

More recently, innovation and expansion in production technology further enhanced the competitiveness of gas-fired CC plants. Four decades of innovation in horizontal drilling and hydraulic fracturing (fracking) availed abundant and cheap unconventional natural gas resources (Fig. 5). These efforts leveraged initial government support but later benefited from substantial private investment in both technology innovation and supply chain expansion. The subsequent decline in natural gas prices further improved the competitiveness of the efficient, relatively new gas-fired generation fleet. Therefore, the energy transition story that has been making headlines in recent years is that of generation switching from coal to natural gas rather than fossil to wind or other renewable technologies.

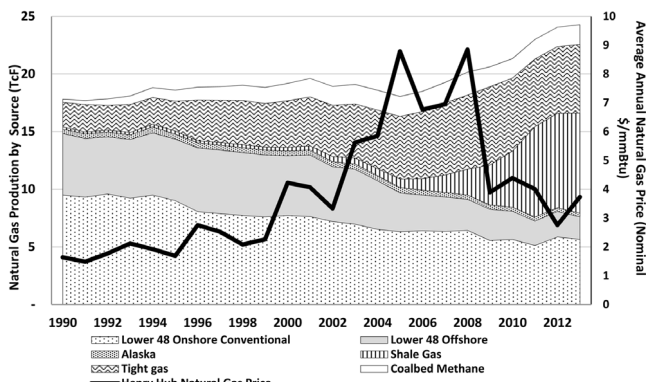
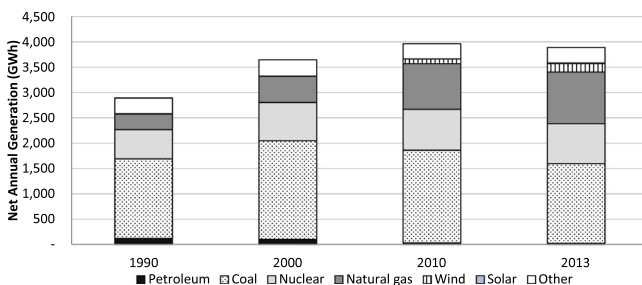
The profound shifts in the power market over the last two decades were not anticipated when PTC and RPS rules were conceived. Two decades after the initiation of the PTC, the contribution of wind to the energy mix of the US reached 4% while the share of fossil-fired generation remained roughly the same at 67%. Overall energy requirements rose by one third indicating that natural gas was relied upon to support demand growth, replace retired facilities, and displace generation from older less-efficient fossil-based technologies (Fig. 6). The fierce competition among fossil-fueled technologies made ambitious wind energy penetration targets much harder to achieve than originally perceived in the EPAct of 1992. Note that although surveys revealed that the public is in favor of wind energy over natural gas from an environmental

Table 1

Primary federal and state policy instruments supporting wind energy penetration in the US.

Source: KAPSARC, using data from multiple state and federal sources

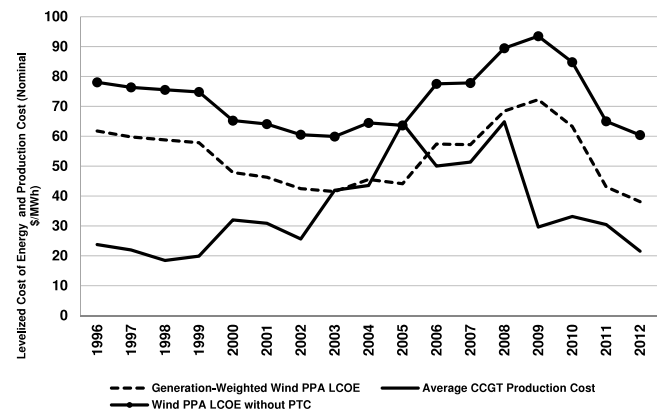
Year	PTC Status	States enacting RPS policy	States facing RPS compliance deadlines
1990			IA
1992	Introduced by the EPAct of 1992		
1997		NV	
1998		CT	
1999	Renewed by the Ticket to Work & Work Incentives Improvement Act of 1999	ME, NJ, TX, WI	
2001		HI	
2002	Renewed by the Job Creation and Worker Assistance Act of 2002	CA, MA	
2003			MA
2004	Renewed by the Working Families Tax Relief Act of 2004	CO, MD, NY, PA, RI	
2005	Renewed by the EPAct of 2005	DC, DE, MT	NV
2006	Renewed by the Tax Relief and Health Care Act of 2006	AZ, WA	AZ, MD
2007		IL, MN, NC, NH, NM, OR	CO, DC, DE, PA, RI, TX
2008	Renewed by the Emergency Economic Stabilization Act of 2008	MI, MO, OH	ME, MT, NJ
2009	Renewed by the American Recovery & Reinvestment Act of 2009	KS, WV	IL, NH, OH
2010			CA, CT, HI, MN
2011			KS, NM, OR
2012	Renewed by the American Taxpayer Relief of 2012		MI, NC, WA, WI
2013			MO
2014	Expired		

**Fig. 5.** Historical US natural gas price (Henry Hub Index on the right-hand side) and supply by source category (left hand side) for the years 1990 through 2013. Source: Data based on EIA and BP 2013 Statistical Review of World Energy data.**Fig. 6.** Historical generation in the US by fuel type (Data based on the EIA March 2014 Monthly Energy Review data).

aspect (Davis and Fisk, 2014), natural gas continued to grow given its falling costs.

It may be near impossible for state and federal policymakers to exactly predict how advancements in incumbent fuel extraction and subsequent power generation, if any, may evolve. Still, incorporating potential tightening competitive dynamics could be useful for avoiding the cliff-effect¹ in renewable capacity investments as incentives expire (Fig. 4).

¹ The cliff effect is the collapse in investment that occurs when one incentive program expires before policymakers realize there is a need for a successor scheme.

**Fig. 7.** Levelized cost of energy of natural gas-fired combined cycle and wind technologies in the US (1996–2012).

Source: KAPSARC using data from EIA, BP, and Lawrence Berkeley National Lab (LBNL)

The natural gas spikes in 2004–2005 could have tempted policymakers to consider the job of advancing wind technologies done. But this would have been premature. The cost of producing electricity from wind was still higher than that of natural gas-fired CC facilities. Incumbent technology innovation and supply chain development has caused a reduction in natural gas-fired CC levelized cost of energy (LCOE). Despite the considerable reduction in wind LCOEs, they were still significantly higher than their combined-cycle gas turbine (CCGT) counterparts in 2012 with or without incorporating the policy support (Fig. 7). Essentially, the advancements that occurred in fracking stunted growth in wind and even other technologies as analyzed in Sovacool (2014).

3. Discussion and evaluation of results

3.1. Answering research question 1

Using two well-known renewable energy transition case studies, potential transformations in the competitive landscape that are typically overlooked in policy design have been identified. These blind-spots essentially answer our first research question, which pertains to identifying unintended consequences to energy transition policy.

Germany's energy transition journey exemplifies the complexities arising from trying to achieve local industry development

targets and high penetration targets, simultaneously, within a tight timeframe (Haralambopoulos and Polatidis, 2003). With hindsight, we can say that policy has overlooked the potential competitive pressures that could have arisen from global suppliers, inhibiting the achievement of local goals. The German experience also demonstrates how underestimating future cost reductions in the renewable energy being supported can result in transmuting a reasonable financial incentive to a profligate one, and consequently causing political controversy trying to agree on policy amendments. Scenario planning and asking ‘what-if’ questions are routes to mitigating the associated uncertainty (Mourmouris and Potolias, 2013). Equivalently, policies can be designed with flexibility attached to them to adapt for potential changing market conditions.

In the US, regardless of the numerous federal and state policy instruments that were devised to support wind energy penetration, the natural gas value chain continued to improve its competitiveness in both the production of fuel and conversion to electricity. The latter is true and is independent of changing demand levels. These improvements, which were not competitive reactions to wind industry growth, changed the landscape for all power generating technologies. We can imagine that this progress will continue, even assuming policy driven support for a new technology does not eat into the market share of the incumbent. It will therefore take longer than originally imagined by policymakers for the new entrant to become cost competitive in its own right. The high reliance of wind energy development on incentives for more than 20 years since the introduction of the wind PTC is an example. However, if the new entrant secures so great a penetration that demand for the incumbent begins to decline in absolute terms, the decline in demand will make the incumbent technology more cost-competitive. This additional consequence of competition will further prolong the need for policy support for the new entrant.

The cost competitiveness discussed above (including Fig. 7), was based on the LCOE. Certainly, comparing generation costs using the LCOE is not fully fair as the LCOE does not capture the intermittency limitation that is inherent to renewables. Nonetheless, the LCOE is still reasonable for general indicative purposes and is still considered the most widely used metric for comparing generation technologies within the energy circle, especially in the absence of other methodologies. Both the benefits and limitations of using the LCOE have been well documented in the literature (Ouyang and Lin, 2014; Ueckerdt et al., 2013).

The scale and duration of financial commitments by governments are undoubtedly an important aspect of any policy, and the case studies tell us that policy suppleness with respect to the finances can prevent creating political controversy at later stages of policy implementation (White et al., 2013). Two characteristics of a supply policy are of particular importance; the first is concerned with the ability to reduce or cease financial support dedicated to a specific technology if the technology costs fall for whatever reason. The German case-study (i.e. second blind-spot) reflects the value of this option in the face of technology costs falling faster than anticipated.

In the alternative case of renewable technology costs not falling as fast as those of incumbent fossil fuel supply chains, the danger is different. If the aim of policies supporting renewable energy is achieved – absolute reductions in consumption of fossil fuels – an economy may suffer higher energy prices than its competitors relying on fossil fuels. Renewables are only competitive with conventional fuels when their full cycle costs are comparable to the costs rather than the current market prices of fossil fuels. The continuing excess costs of renewables can only be borne by one of three stakeholders: investors (and their lenders), consumers, and taxpayers. These higher energy costs are locked in once the capacity is installed, because of the high capital, low operating costs of wind and solar electricity. Furthermore, unless investors

are coerced, there is a maximum contribution they will make based on their rate of return requirements. This leaves the balance to be shared between taxpayers and consumers, either directly or indirectly.

It is not hard to imagine that governments seeking to bolster their economies will succumb to the temptation to reduce the costs of support to their transition strategies. This may cause investors relying upon incentives to fill the cost gap in their economic comparisons of conventional and renewable energy to hold back or require levels of commitment that are politically difficult to provide.

3.2. Answering research question 2

Based on these three blind-spots presented, and to answer our second research question, a general framework may aid policymakers in securing a higher likelihood of success. This reinforces the value of understanding, and being mindful of risk, uncertainty, and system effects.

- Risk effects can be predicted with some confidence, but deviations are also possible. The learning curve and economies of scale concepts are examples of this type of risk. It is reasonable to assume certain reductions in the manufacturing costs of a technology based on its learning curve, but there are no guarantees that these outcomes will occur exactly as predicted.
- Uncertainty effects are associated with events of an unknown probability distribution, including recessions and radical engineering innovations.
- System effects are those associated with the market and its potential equilibrium, including the actions of other countries. Suppliers entering or leaving a market will affect prices and costs and alter the likelihood of achieving a target or the expense of doing so.

There is value to policymakers in assessing the effects of their policy on market equilibria conditions both domestically and abroad. They are less likely to be wrong-footed if, beyond the current global supply and demand environment, they understand future targets that other countries have set for themselves. The robustness of the policy choices under both risk and uncertainty effects can be assessed (Bruno et al., 2016). In fact, and put in another way, some authors have actually posited that there is room for global policy coordination which in turn can help in achieving targets more effectively (Grau et al., 2012).

3.3. Application in models

While the future cannot be predicted, policymakers can attach a degree of flexibility to policies to allow expected and unexpected future events to be tolerated and even to capitalize on them. This type of scenario planning can yield dividends. Based on the three blind-spots identified in this paper, we provide a single exemplary possible application only for each blind-spot in a modeling exercise, although many examples and applications could be given.

With respect to the first blind-spot, i.e. demand outstripping local industry capacity, it can play an important role in any effort related to supply chain modeling. How quickly can supply chains expand and/or respond to various demand levels are all quantifiable metrics in the supply chain management field. One important parameter in supply chain modeling that used to ensure stable inventory orders/quantities is the safety stock parameter, which relates to the inventory amount that prevents out-of-stock situations due to demand fluctuations or disruptions in the supply chain (Carbonara and Pellegrino, 2017; Diabat et al., 2017). A variance is tied to this parameter for estimation and forecasting purposes. By

understanding global renewable energy policy dynamics, vendors can arrive at the safety stock parameter and its variance with more clarity.

The second blind-spot, i.e. rapid reduction in costs of new technologies, can be useful in dynamic optimization models. In fact, the authors in Wand and Leuthold (2011), for example, do exactly that and develop a dynamic optimization model for examining policy effectiveness resulting from induced learning curves with an emphasis on the solar PV industry. They developed three self-explanatory scenarios: a 'business-as-usual' scenario, an 'economic growth' scenario, and a 'sunny future' scenario. Each scenario implied certain spending, penetration rates, and added generation. It was thus possible to formulate a general idea of each scenario's outcome and the challenges for policy that would arise.

It appears that Germany's EEG assumed only a business-as-usual scenario in initial policy design, while reality followed a sunny-future path, or at least an economic growth path. There was an opportunity to prepare for different futures than expected – the most robust policy would have been one that was resilient to a range of scenarios or one that identified the actions that would need to be taken should a deviation from the anticipated scenario arise and to incorporate it at an administrative, rather than legislative level.

Finally, the last blind-spot, i.e. cost reductions in conventional technologies, would be insightful in macro-econometric models describing fossil-fuel-rich economies in particular (Hasanov et al., 2017). Countries with economies concentric about fossil-fuels would welcome advancements in conventional generation technologies as it increases their export competitiveness and consequently drives economic growth, and also makes the road ahead of renewables longer (Shah et al., 2018). Furthermore, advancements in conventional technologies would also allow, or necessitate, revising subsidy levels tied to power generation (Blazquez et al., 2017).

4. Conclusions

An important lesson to be elicited from the case studies presented is that competitive pressures exercised on the new technology may be intentional or unintentional. These dynamics arise from myriad forces: domestic and foreign, technology- and market-driven. In the US, the advancements in CCGT and fracking have not occurred intentionally in retaliation to renewable energy development. Conversely, the expansion of the PV industry in China may have been a deliberate attempt to compete with the PV sector in Germany as part of China's overall policy initiative to promote export-related industries.

Policymakers are well advised to remember that demand for fossil fuels has been rising throughout the past decade, reducing the need to focus on competitiveness of such fuels to defend market shares. However, if transition policies are successful, there is no guarantee that this will continue to be the case. Demand on fossil fuels may clear lower down the cost of supply curves and, further, the curves themselves will likely move downwards as innovation counters the threat of extinction.

It may seem that this paper is contradicting itself by asking policymakers to try to anticipate dynamics that are difficult to foretell. While predicting the future accurately is impossible, it is both feasible and helpful to incorporate a range of potential scenarios for the evolution of the competitive landscape. Just because energy transitions may take longer and cost more than currently foreseen does not mean that they should not be undertaken. However, policies are more likely to be sustainable if they incorporate resilience to "inconvenient" outcomes as well as to the "preferred" state of the world.

Policies can be designed with flexibility to adapt to potential changes in the competitive landscape. Otherwise, policymakers

may be criticized for shortcomings that were certainly evident with the benefit of hindsight but could also have been reasonably foreseen.

References

- Bazilian, M., Onyeji, I., Liebreich, M., Macgill, I., Chase, J., Shah, J., Gielen, D., Arent, D., Landfear, D., Zhengrong, S., 2013. Re-considering the economics of photovoltaic power. *Renew. Energy* 53, 329–338.
- Beermann, J., Tews, K., 2017. Decentralised laboratories in the German energy transition. Why local renewable energy initiatives must reinvent themselves. *J. Cleaner Prod.* 169, 125–134.
- Blazquez, J., Fuentes-Bracamontes, R., Bollino, C.A., Nezamuddin, N., 2018. The renewable energy policy Paradox. *Renew. Sustain. Energy Rev.* 82, 1–5.
- Blazquez, J., Hunt, L., Manzano, B., 2017. Oil subsidies and renewable energy in Saudi Arabia: A general equilibrium approach. *Energy J.* 38, 29–45.
- Bruno, S., Ahmed, S., Shapiro, A., Street, A., 2016. Risk neutral and risk averse approaches to multistage renewable investment planning under uncertainty. *European J. Oper. Res.* 250, 979–989.
- Bryman, A., 2017. Quantitative and qualitative research: further reflections on their integration. In: *Mixing methods: Qualitative and quantitative research*. Routledge.
- BSW, 2014. Statistic data on the German Solar power (photovoltaic) industry [Online]. Available: http://www.solarwirtschaft.de/fileadmin/media/pdf/2013_2_BSW-Solar_fact_sheet_solar_power.pdf [Accessed 03.03.17].
- Carbonara, N., Pellegrino, R., 2017. How do supply chain risk management flexibility-driven strategies perform in mitigating supply disruption risks? *Int. J. Integr. Supply Manag.* 11, 354–379.
- Cheng, Q., Yi, H., 2017. Complementarity and substitutability: A review of state level renewable energy policy instrument interactions. *Renew. Sustain. Energy Rev.* 67, 683–691.
- Davis, C., Fisk, J.M., 2014. Energy abundance or environmental worries? Analyzing public support for fracking in the United States. *Rev. Policy Res.* 31, 1–16.
- Diabat, A., Dehghani, E., Jabbarzadeh, A., 2017. Incorporating location and inventory decisions into a supply chain design problem with uncertain demands and lead times. *J. Manuf. Syst.* 43, 139–149.
- Enevoldsen, P., Valentine, S.V., Sovacool, B.K., 2018. Insights into wind sites: critically assessing the innovation, cost, and performance dynamics of global wind energy development. *Energy Policy* 120, 1–7.
- Fan, P., Watanabe, C., 2006. Promoting industrial development through technology policy: Lessons from Japan and China. *Technol. Soc.* 28, 303–320.
- Fang, L., Honghua, X., Sicheng, W., 2014. National Survey Report of PV Power Applications in China.
- Fischlein, M., Feldpausch-parker, A.M., Peterson, T.R., Stephens, J.C., Wilson, E.J., 2014. Which way does the wind blow? Analysing the state context for renewable energy deployment in the United States. *Environ. Policy Governance* 24, 169–187.
- Fischlein, M., Larson, J., Hall, D.M., Chaudhry, R., Peterson, T.R., Stephens, J.C., Wilson, E.J., 2010. Policy stakeholders and deployment of wind power in the sub-national context: A comparison of four US states. *Energy Policy* 38, 4429–4439.
- Fouquet, R., Pearson, P.J., 2012. Past and Prospective Energy Transitions: Insights from History. Elsevier.
- Fronzel, M., Ritter, N., Schmidt, C.M., 2008. Germany's solar cell promotion: Dark clouds on the horizon. *Energy Policy* 36, 4198–4204.
- Fronzel, M., Ritter, N., Schmidt, C.M., Vance, C., 2010. Economic impacts from the promotion of renewable energy technologies: The German experience. *Energy Policy* 38, 4048–4056.
- Gamal, R.E., Shamseddine, R., Paul, K., 2017. PRT-Saudi Arabia pushes ahead with renewable drive to diversify energy mix [Online]. Available: <http://www.reuters.com/article/saudi-renewable/rpt-saudi-arabia-pushes-ahead-with-renewable-drive-to-diversify-energy-mix-idUSL8N1HP1EO> [Accessed 26.01.18].
- Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017. The socio-technical dynamics of low-carbon transitions. *Joule*.
- Goodrich, A.C., Powell, D.M., James, T.L., Woodhouse, M., Buonassisi, T., 2013. Assessing the drivers of regional trends in solar photovoltaic manufacturing. *Energy Environ. Sci.* 6, 2811–2821.
- Grau, T., Huo, M., Neuhoof, K., 2012. Survey of photovoltaic industry and policy in Germany and China. *Energy policy* 51, 20–37.
- Grubler, A., 2012. Energy transitions research: Insights and cautionary tales. *Energy Policy* 50, 8–16.
- Haralambopoulos, D., Polatidis, H., 2003. Renewable energy projects: structuring a multi-criteria group decision-making framework. *Renew. Energy* 28, 961–973.
- Hasanov, F., Bulut, C., Suleymanov, E., 2017. Review of energy-growth nexus: A panel analysis for ten Eurasian oil exporting countries. *Renew. Sustain. Energy Rev.* 73, 369–386.
- Hoppmann, J., Huenteler, J., Girod, B., 2014. Compulsive policy-making—The evolution of the German feed-in tariff system for solar photovoltaic power. *Res. Policy* 43, 1422–1441.

- Huo, M.-L., Zhang, D.-W., 2012. Lessons from photovoltaic policies in China for future development. *Energy Policy* 51, 38–45.
- IEA, 2013. Trends in Photovoltaic Applications.
- Institute, E.P., 2014. Eco-economy Indicators - Solar Power.
- Kasap, S., Capper, P., 2017. Springer Handbook of Electronic and Photonic Materials. Springer.
- Liu, J., Goldstein, D., 2013. Understanding China's renewable energy technology exports. *Energy Policy* 52, 417–428.
- Lund, P.D., 2009. Effects of energy policies on industry expansion in renewable energy. *Renew. energy* 34, 53–64.
- Mattlin, M., 2009. Chinese strategic state-owned enterprises and ownership control. In: BICCS Asia Paper, Vol. 4. pp. 1–28.
- Moosavian, S., Rahim, N., Selvaraj, J., Solangi, K., 2013. Energy policy to promote photovoltaic generation. *Renew. Sustain. Energy Rev.* 25, 44–58.
- Mourmouris, J., Potolias, C., 2013. A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: A case study Thassos, Greece. *Energy Policy* 52, 522–530.
- Mundo-hernández, J., De Celis Alonso, B., Hernández-Álvarez, J., De Celis-Carrillo, B., 2014. An overview of solar photovoltaic energy in Mexico and Germany. *Renew. Sustain. Energy Rev.* 31, 639–649.
- O'Sullivan, K., Howden-Chapman, P., 2017. Mixing methods, maximising results: Use of mixed methods research to investigate policy solutions for fuel poverty and energy vulnerability. *Indoor Built Environ.* 26, 1009–1017.
- Ouyang, X., Lin, B., 2014. Levelized cost of electricity (LCOE) of renewable energies and required subsidies in China. *Energy Policy* 70, 64–73.
- Pegels, A., Lütkenhorst, W., 2014. Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV. *Energy Policy* 74, 522–534.
- Reichelstein, S., Yorston, M., 2013. The prospects for cost competitive solar PV power. *Energy Policy* 55, 117–127.
- Saidur, R., Islam, M., Rahim, N., Solangi, K., 2010. A review on global wind energy policy. *Renew. Sustain. Energy Rev.* 14, 1744–1762.
- Shah, I.H., Hiles, C., Morley, B., 2018. How do oil prices, macroeconomic factors and policies affect the market for renewable energy? *Appl. Energy* 215, 87–97.
- Solomon, B.D., Krishna, K., 2011. The coming sustainable energy transition: History, strategies, and outlook. *Energy Policy* 39, 7422–7431.
- Sovacool, B.K., 2014. Cornucopia or curse? Reviewing the costs and benefits of shale gas hydraulic fracturing (fracking). *Renew. Sustain. Energy Rev.* 37, 249–264.
- Sovacool, B.K., Axsen, J., Sorrell, S., 2018. Promoting novelty, rigor, and style in energy social science: towards codes of practice for appropriate methods and research design. *Energy Res. Soc. Sci.*
- Stenzel, T., Frenzel, A., 2008. Regulating technological change—The strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets. *Energy Policy* 36, 2645–2657.
- Ueckerdt, F., Hirth, L., Luderer, G., Edenhofer, O., 2013. System LCOE: What are the costs of variable renewables? *Energy* 63, 61–75.
- Von Geibler, J., Biege, K., Schüwer, D., Berthold, O., Dauensteiner, A., Grinewitschus, V., Hoffmann, D., Renner, W., Ostermeyer, Y., 2018. Identifying business opportunities for green innovations: A quantitative foundation for accelerated micro-fuel cell diffusion in residential buildings. *Energy Rep.* 4, 226–242.
- Wand, R., Leuthold, F., 2011. Feed-in tariffs for photovoltaics: Learning by doing in Germany? *Appl. Energy* 88, 4387–4399.
- Weick, C.W., Jain, R.K., 2014. Rethinking industrial research, development and innovation in the 21st century. *Technol. Soc.* 39, 110–116.
- White, W., Lunnan, A., Nybakk, E., Kulisic, B., 2013. The role of governments in renewable energy: The importance of policy consistency. *Biomass Bioenergy* 57, 97–105.
- Yu, H.J.J., Popiolek, N., Geoffron, P., 2016. Solar photovoltaic energy policy and globalization: a multiperspective approach with case studies of Germany, Japan, and China. *Prog. Photovolt., Res. Appl.* 24, 458–476.
- Yu, C., Van Sark, W., Alsema, E., 2011. Unraveling the photovoltaic technology learning curve by incorporation of input price changes and scale effects. *Renew. Sustain. Energy Rev.* 15, 324–337.