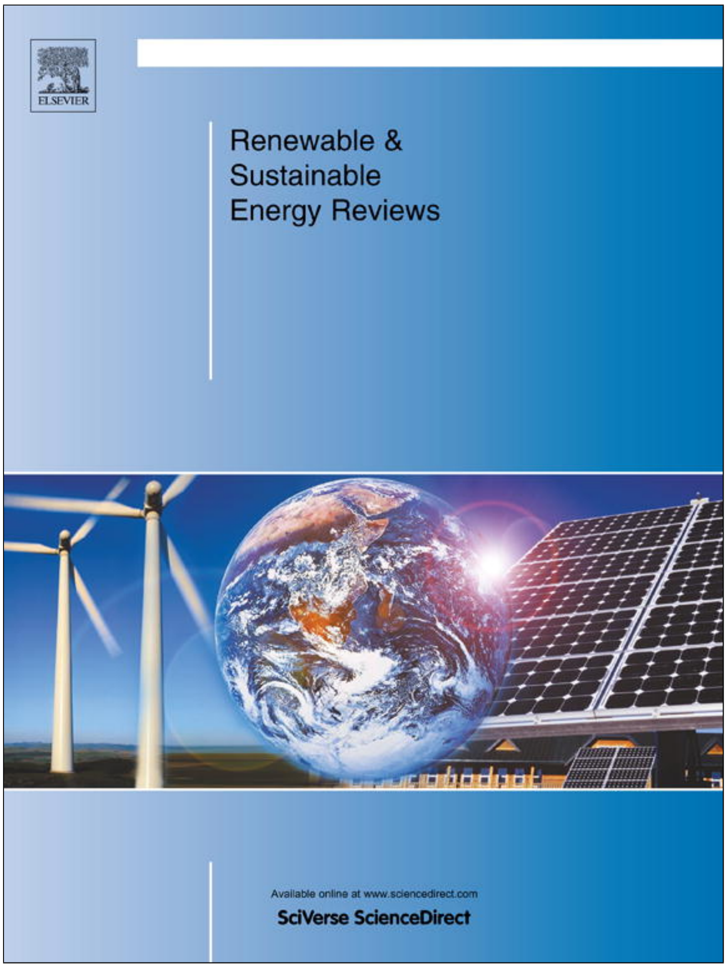

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Wind power policy in complex adaptive markets

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ABSTRACT

This paper aims to advance research into the effectiveness of policies for encouraging technological transition in the energy sector (in general) and wind power (in particular). It contends that the ineffectiveness of wind power development policy in most nations stems from a linear approach to policy design that is unsuited to complex adaptive markets. The paper argues that in complex adaptive markets, policies are required that foster competition on a level playing field. Insights are extracted from complexity theory to advance four principles for effective wind power policy in such markets. These principles include establishing policy initiatives to: encourage technological diversity, establish clear and progressive short to medium-term targets, enhance environmental monitoring systems and establish a malleable policy regime that directly resolves emergent challenges while simultaneously sustaining market momentum to ensure long-term targets are met. In order to demonstrate the applied relevance of these principles, the paper applies these concepts to a historical analysis of Denmark's wind power development policies.

Contents

1. Policy in complex adaptive systems

"Industrial mutation… incessantly revolutionizes the economic structure from within, incessantly destroying the one, incessantly creating a new one [1]".

In 1943, Joseph Schumpter used these words to describe his concept of "creative destruction". Although he was applying the term to a broader concept – understanding the dynamics of capitalism – Schumpter's notion of creative destruction has proven to be of catalytic value in guiding research into the evolutionary dynamics of technological innovation and diffusion. This is because the notion of creative destruction suggests that there is an underlying process which enables the commercialization of new technology, resulting in the demise of incumbent technology.

Traditionally, *process mapping* – gaining a better understanding of the fundamental processes through which technological change occurs – is a requisite first step toward the design of policy for influencing the scale, scope and pace of technological change; however, process mapping is not sufficient in itself for crafting effective policy. The development of effective policy requires two further steps. First, empirical evidence of the applied effectiveness of policy instruments must be collected and contextual biases associated with the findings must be removed to the greatest extent possible [2]. Second, this contextually neutralized empirical evidence must be somehow amalgamated into a cognitive framework to provide policymakers with a conceptual toolkit for guiding policy development. Unfortunately, all stages of this three step policy process – process mapping, policy instrument evaluation and contextual neutralization – are complicated by the nature of modern technology markets.

Technology evolves amidst a "seamless web" of technical, social, political and economic causal factors that supports the

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development of a specific technological regime [3]. The number of key influential variables and the scale and scope of interdependencies between variables are so extensive within these seamless webs that the prediction of technological evolution is fraught with risk [4]. This is evidenced by the vibrancy and volatility of technology stocks.

Market conditions where unpredictability reigns are known as *complex adaptive markets* (CAMs) [5]. In strategic management theory, the unpredictability of complex adaptive markets necessitates that the linear nature of traditional strategic planning be replaced by a more malleable approach that emphasizes sophisticated levels of market monitoring and the establishment of mechanisms which facilitate expedient response to emergent opportunities [6]. Yet, in regard to technology policy within complex adaptive markets, policy is still guided by linear models that emphasize prescribed solutions that – in theory – produce relatively predictable results. It should come as no surprise that, as a consequence of this, technology policy frequently fails to achieve the intended results.

The challenge of developing policy to effectively enhance the diffusion of wind power exemplifies the ineffectiveness of employing linear policy models to facilitate change in complex adaptive markets. Globally, wind power contributes less than 2% to electricity systems, despite the commercial viability of wind power and the global imperative to expedite a transition away from CO_2 intensive energy technologies in order to abate the more severe social, economic and ecological consequences associated with advanced stages of climate change [7,8].

The goal of this paper is to examine wind power diffusion policy from the perspective of complexity theory in order to shed light on the short-comings of the traditional approach to wind power policy development and provide new directions for research into policy prescriptions that better guide development in complex adaptive markets. Although the context of the paper is wind power development, it is held that the principles espoused in this analysis hold relevance for technology policy in all complex adaptive markets.

The paper attempts to make at least two theoretical contributions. First, it presents a critical review of the ideology that currently guides technology policy and in the process, introduces a more comprehensive perspective on how technology evolves within complex adaptive markets. The analysis produces a new dialectic on technology development that highlights the possibility of a successful market defense by the incumbent technology, which when applied to wind power development policy identifies a need for policy responses that are all too often neglected in national wind power development policy. Second, the paper advances a *complex adaptive market* perspective on designing responsive policy to manage the nation-specific web of social, technological, economic and political factors that influence technological transition and provides a degree of empirical validation for its applied relevance, albeit in one technological context (energy) in one national context (Denmark).

From an applied energy policy perspective, this paper also serves to catalogue the evolutionary nature of energy policy in Denmark, challenging the common perception that Denmark's success in wind power development was the result of consistent policy. In doing so, it highlights the importance of effectively monitoring market dynamics and creating policy to respond to emergent needs in order to thwart problems that might otherwise derail market development.

The next section represents the theoretical foundation of the paper, beginning with a critical review of perspectives on technological change. It then critiques the well-entrenched linear approach to policy development and draws from complexity theory to introduce four principles for policymaking in complex adaptive markets. Section three reviews the major wind power policy developments in Denmark from 1970–2010 to demonstrate how these four principles played a role in catalyzing wind power diffusion in Denmark. Finally, section four concludes and offers some suggestions for further research.

2. Perspectives on technological change

2.1. Toward a new dialectic

As mentioned in the introduction, gaining a better understanding of the fundamental processes through which technological change occurs is a requisite first step toward the design of policy for influencing the scale, scope and pace of technological change.

Fig. 1 presents a dialectic which summarizes the dominant perspectives on technological transition. The critical variable governing this dialectic is "*pace of change*". On one side of this dialectic, truly transformational technological change is viewed as the product of a *paradigm shift*—a technological development that is so radically different from the status quo that it changes the manner in which the technology is perceived and catalyzes widespread adoption. For example, one might argue that the release of the IBM personal computer and the compatible word processing software, Wordstar catalyzed a paradigm shift in word processing that until that time was dominated by the electric typewriter.

On the other side of this "pace of change" dialectic is the notion that transformational change is a result of a series of "incremental" changes that are by and large path dependent—previous change begets conditions which frame future change [9]. Relating this back to the word processing example, advocates of the incremental change perspective would point out that there were a number of small innovations that enabled computerized word processing. In the lead-up to the launch of IBM's PC and the Wordstar program, innovation groups were developing elaborate computer coding techniques, enhancing random access memory, improving user interfaces and driving hundreds of other advances that eventually made the launch of the personal computer possible. In other words, change was not sudden; it was gradual and cumulative.

In attempting to synthesize these two perspectives on how technology evolves, a concept from evolutionary biology has been invoked—punctuated equilibrium. Merriam–Webster's dictionary defines punctuated equilibrium as "evolution that is characterized by long periods of stability… and short periods of rapid change". Applying this notion to the dialectic of "change as

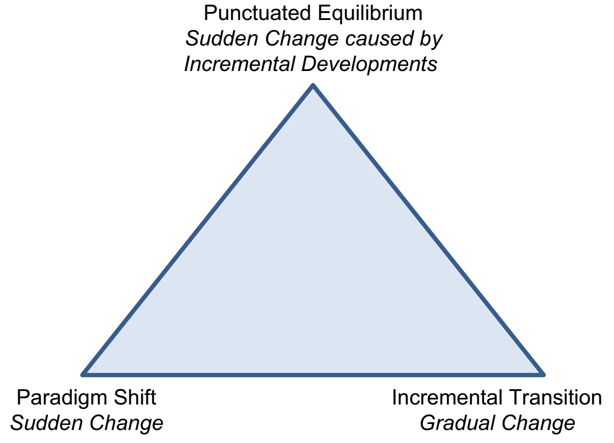


Fig. 1. "Pace of change" dialectic.

a paradigm shift'' versus ''change as incremental evolution'', the punctuated equilibrium perspective contends that incremental changes occur both endogenously – within a technological niche – and exogenously – from the broader external technological environment. During the lead up to technological transition, new technologies emerge, but they exhibit commercial disadvantages that curtail adoption (i.e. the cost of PCs). Consequently, the dominant technology remains entrenched. However, continued incremental improvements to the commercial viability of the new technology eventually produce a situation wherein the benefits of change become irresistible to consumers and change suddenly occurs in an expedient manner that appears to epitomize a paradigm shift; but the event is actually the result of cumulative incremental changes that over time tips the balance in favor of the new technology.

Applying this dialectic to wind power development policy, the notion of punctuated equilibrium suggests to policymakers that policy directed at facilitating incremental change across an array of influential variables is desirable. The goal is to tip the balance in favor of the new technology. Accordingly, policy directed at reducing the cost of wind power (i.e. research subsidies, market adoption incentives), internalizing the full cost of fossil fuel use (i.e. carbon taxes, removal of coal subsidies), and reducing NIMBY (not in my backyard) opposition all represent initiatives that can potentially catalyze wide-scale transition to wind power.

Unfortunately, this dialectic fails to address the confounding influence of a key characteristic associated with competitive, complex adaptive markets—vendors of incumbent technologies are rarely complacent. Although new technologies evolve, so do entrenched technologies. Leveraging the financial advantages associated with mature, market leading technology, vendors of incumbent technologies are typically able to finance massive R&D efforts which can radically alter the market appeal of an incumbent technology—permitting the reigning technology to defend status quo or even affect technological lock through progressive technological development. Carbon Capture and Sequestration (CCS) research efforts illustrate this phenomenon. Billions of dollars are being invested in the quest for commercially viable CCS technologies. If successful, these efforts could significantly stymie attempts by the wind power industry to take market share away from coal power. In fact, taken to an extreme, a commercially viable CCS technology might incapacitate unsubsidized wind power development efforts.

This suggests that the emergence of a new dominant technology represents only one of two possible ''punctuated change'' outcomes—the other possibility is that the incumbent technology is reinvented to retain market dominance. Thus, the variables of this ''complex adaptive market'' dialectic become *contended ascendancy*, *incumbent reinvention* and *punctuated change* (Fig. 2).

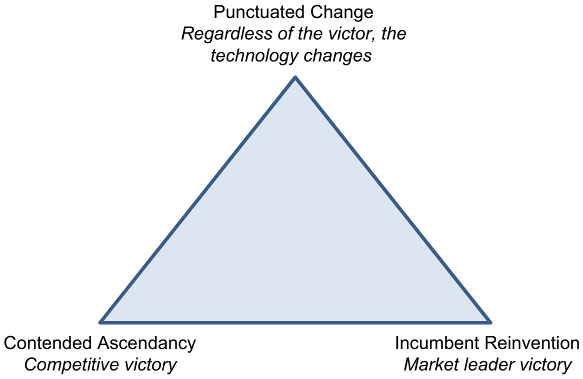


Fig. 2. Complex adaptive market dialectic.

Contended ascendancy describes a transition wherein the merits of a new technology eventually erode the strategic defenses put up by incumbent technology vendors. In such a scenario, the transition is not marked by a rapid change; but rather by slow progression which erodes the market share of the incumbent technology until a point is reached where the accumulated financial might is enough for the challenging technology to defeat the strategic defenses employed by incumbent technology vendors. Conversely, *Incumbent reinvention* refers to a transition wherein the incumbent technology is able to technologically defeat the challenging technology through innovation. In this scenario, a competing technology emerges and begins to make gradual market in-roads until technological improvements to the incumbent technology materialize, allowing the incumbent regime to successfully repel the competitive challenge. In short, *punctuated change* occurs; however, there is no guarantee that the emerging victor is the technology that challenges the incumbent.

This perspective, which acknowledges the possibility of a market defense by an incumbent technology is vital to the development of effective wind power policy (or other technology policy in complex adaptive markets) because it forces policy makers to consider market developments that they would otherwise neglect. This new perspective conveys the lesson that in complex adaptive markets, the diffusion of technology is not solely premised upon economic advantage. Thanks to a pervasive commitment to enhanced market intelligence, vendors of incumbent technologies begin implementing market defense strategies well before new technologies are introduced to a market. Such strategies can include, inter alia, (i) mechanisms which impose switching costs, (ii) strategic alliances with key stakeholders that can inhibit adoption of new technology and (iii) enhanced lobbying efforts to engender social and political resistance to change. These strategies complicate rational economic analysis and can slow down the pace of technological diffusion or derail the process altogether.

As applied illustrations of these strategies, consider the defensive responses of coal-fired technology interest groups as vendors of wind power technology continue to erode coal power's historic economic advantage. The first type of defense – a switching cost strategy – is exemplified by the prominence of long-term fixed contracts for the purchase of coal, which have the strategic effect of locking utilities into longer-term commitments to this form of electricity generation. The second type of defense – strategic alliances – is exemplified by research alliances that have developed between coal-fired technology vendors, coal producers and utilities in order to advance CCS technology. Despite no evidence of commercial viability, the promise of a CCS solution, has in many respects, been enough to engender continued political support for coal power. The third type of defense – lobby efforts – is epitomized by coal industry-sponsored research efforts designed to complicate comparative economic analysis and lobbyist efforts designed to sway energy policy in favor of supporting coal-fired electricity production. In short, as these examples illustrate, strategic efforts on the part of incumbent technologies to defend market share engender a period of competitive incertitude; during which time, forces behind a decisive ''punctuated'' change are only partially successful at displacing the incumbent technology. In such circumstances, policy may be needed to ensure that the financial strength of a dominant technology does not lead to technological transitions that would not otherwise be selected as technologically preferable.

Applied specifically to wind power policy, this perspective highlights the need for policy to actively confront campaigns designed to misinform the public and engender political support for unproven technologies, such as CCS, that might allow coal-fired special interest groups to sway national energy policy. The overarching goal of any national energy policy should be to establish conditions which nurture competition between new technology and incumbent technology because free market competition fosters innovation and improves economic efficiency [10]. However, ensuring a level playing field is exacerbated by the reality that an emergent technology must compete as an underdog, both in terms of closing technological divides and matching the financial strength of the incumbent technology vendors. Therefore, it is a widely agreed tenet of renewable energy policy that policy support is necessary to level the competitive playing field in order to allow emergent technologies to compete on a basis that is not distorted by historical advantage accrued by the incumbent technology [11,12].

In summary, the "complex adaptive market" dialectic highlights an important facet of public policy that tends to be neglected when approaching policy design from the perspective of the "change of pace" dialectic—incumbent technology vendors accrue financial, political and market power through cumulative economies that can be strategically used to block the ascendance of a technology that would emerge victorious if the competition took place on a level playing field. Policy which fails to level the playing field will produce suboptimal results.

2.2. *Modifying complexity strategy for public policy use*

As mentioned in the first section, the unpredictable nature of complex adaptive markets renders the traditional approach to policy design ineffective. Traditionally, policy design has been perceived as a linear process—a desired policy outcome is established, a policy instrument is selected to affect change, the policy is implemented and barring unexpected obstacles, the desired outcome is more or less achieved. In energy policy, a vast body of literature demonstrates this type of linear thinking as researchers search for universal policy solutions. Research has been published which champions inter alia carbon trading [13], carbon taxes [14], feed-in tariffs [15], enhanced R&D [16], government regulations [17], enhanced efficiency standards [18], a ban on coal [19], government-controlled energy sector development [20] and even a regulatory approach to incentivization [21]. Although these findings are valid within the context in which they were observed, the quest for a universal model to guide policy has been elusive.

Recently, one analyst, Clara Garcia, has attempted to fill this lacunae by presenting a list of "best practices" for enhancing renewable energy development. Garcia has proposed six policy principles for overcoming economic barriers faced by emerging technologies which include: (i) the elimination of coal subsidies, (ii) compensation for the negative externalities of fossil fuels, (iii) remuneration for the positive externalities of renewables, (iv) compensation for high initial costs, (v) increased access to capital and (vi) mechanisms to ensure sufficient demand. Garcia has further advocated five institutional principles for overcoming the non-economic barriers faced by emerging technologies. These include institutional initiatives to ensure (i) general legal security, (ii) capable bureaucracy, (iii) quality of regulations in renewables, (iv) competition and technology-friendly policies in generation, and (v) competition and technology-friendly policies in manufacturing [22]. Unfortunately, as appealing as this list appears to be, the universal applicability of these 11 principles does not stand up to empirical scrutiny for at least three reasons.

First, as energy technologies evolve along the developmental path – from inception to adoption to growth through to maturity – proponents of the technology face assorted hurdles that require varying types of policy support. Not every one of Garcia's best practice principles is relevant at each stage of the technological evolution. For example, China has achieved success in wind power manufacturing by initially insulating its domestic wind turbine manufacturers from direct competition, contravening one of Garcia's principles of best practice. Although the nation is now liberalizing competition in the wind power sector, erecting market barriers at the inception proved to be instrumental for nurturing a domestic industry that is now considered to be an attractive cogs in the nation's industrial development strategy [23].

Second, best practice should not be thought of as a dichotomous exercise, as Garcia's list implies. For example, it is not enough to simply provide "compensation for high initial costs" in order to encourage investment in emergent energy technologies; rather, an appropriate level of compensation must be provided in order to establish a pace of diffusion that can be supported socially, technologically, economically and politically. For example, failure to establish a large enough feed-in tariff for supporting wind power development has been identified as one of the main hurdles to wind power development in Taiwan [24], Japan [25] and, as this case will demonstrate, even in Denmark during some periods of development.

Third, not all of the best practices enumerated by Garcia are necessarily required to optimize technological diffusion. For example, the best practices of providing "compensation for the negative externalities of fossil fuels" and "remuneration for the positive externalities of renewables" need not be applied in tandem, and indeed, can potentially lead to excesses through double subsidization. For many nations, employing just one of these measures in a quantitatively robust manner could achieve the desired catalytic result. Similarly, if government subsidies are structured in a manner that guarantees suitable market return, policies designed to "increase access to capital" might represent excess subsidization.

The problem with enumerating best practice is that it suffers from the same shortcomings as the research alluded to earlier which attempts to identify optimal policy tools for enhancing renewable energy development—they represent linear solutions to non-linear challenges. Due to the "seamless web" of social, technological, economic and political forces that influence the effectiveness of a given energy policy, predicting how a market will react to a given policy is an exercise in fallibility. The contextual differences between markets convolute the design of universal policy frameworks for optimizing renewable energy diffusion. So, if the traditional linear approach to policy design is not viable, what is the solution?

As alluded to earlier, strategic management theory provides some insights that merit investigation. Traditionally, strategic management theory also embraced linear models for guiding corporate strategy development. Broadly speaking, there were two traditional camps of thought. An *industrial organization* camp embraced a perspective that advocated the exploitation of favorable market conditions as a central tenet [26]. A *resources-based view* camp embraced the perspective that a firm's internal resources should be manipulated to create competitive advantage in a given market [27]. Both are linear perspectives in that they exhibit a belief that if a firm implements initiatives—X and Y, a particular result—Z, will ensue. In the 1990s, this linear perspective came under challenge from complexity theorists who pointed out that the dynamic nature of modern, global markets was such that predicting the emergence of trends (which is instrumental to the success of a linear strategy) was unrealizable. Complexity theorists argued that in order for a firm to ensure continued success in complex adaptive markets, firms needed to; (i) ensure a degree of diversity in order to mitigate risk, (ii) create short-term goals to guide operational activities, (iii) construct sophisticated environmental monitoring systems in order to highlight unexpected market developments and (iv) design malleable corporate structures in order to allow firms to expeditiously change course [5,6].

Since the goal of public policy in complex adaptive markets is to facilitate the achievement of a policy goal, public policy and corporate strategy share a common goal—the manipulation of market dynamics. Consequently, the four fundamental elements of complex adaptive market theory outlined in the previous paragraph might have relevance if adapted to a policy perspective.

In order to adapt the four elements for policy relevance, only minor alterations are required. First, the corporate challenge of ensuring a degree of diversity in order to mitigate risk can be adapted for policy use by restating the goal as ‘‘ensuring that policies support a variety of emerging technologies in order to avoid artificially creating winners at the expense of promising emergent technologies’’. Second, the corporate challenge of creating short-term goals to guide operational activities, can be adapted to the premise, ‘‘establish clear and progressive short and medium term targets in order to signal intent to the market’’. Third, the premise of ‘‘constructing sophisticated environmental monitoring systems in order to highlight unexpected market developments’’ is as valid for policy use as it is for strategic management use; the only difference being the need to monitor more variables (i.e. environmental impact) and seek feedback from a broader base of stakeholders. Fourth, the corporate challenge of designing malleable corporate structures in order to allow firms to expeditiously change course can be adapted for policy use as ‘‘establish a malleable policy regime that directly resolves emergent challenges while simultaneously sustaining market momentum to ensure long-term strategies are met’’. These four principles are summarized in Table 1.

As opposed to a list of best practice principles, these four principles avoid the pitfall of being overly prescriptive. The first principle does not explicate which technologies to support, it only highlights the need for diversity, which is a key element to ensuring a level of competition which forces firms to progressively innovate. The second principle does not quantify what the short and medium term targets should be, it only emphasizes the importance of sending clear and consistent signals to the private market. Given the variety of energy technologies and the competitive pushback from conventional energy technology, policies which signal an intent to support the most economically viable, CO_2-reduced technologies reduce risk and induce investment activity. The third principle does not explicate what needs to be monitored, it only highlights the importance of comprehensively monitoring influential variables within a given national context. For example, in China, NIMBY opposition to wind power projects is not yet an issue of importance; while in the United States, NIMBY opposition to wind power projects is of utmost importance. In both instances, levels of social dissonance may change and it is important that policymakers keep abreast of influential changes in a timely manner. Similarly, the fourth principle does not prescribe what type of policy regime should be constructed to facilitate wind power development, it only highlights the need to infuse the policy regime with a degree of flexibility to allow it to adapt to emergent challenges.

In the next section, the applied relevance of these four principles is demonstrated by showing how Danish policymakers have embraced this type of malleable approach to wind power development policy. The history of wind power development policy in Denmark demonstrates that policy design and implementation is fraught with unanticipated challenges and missteps; but a policy regime that sets progressive goals, learns from its mistakes and adjusts to emergent challenges stands a greater chance to ensure policy outcomes match aspirations.

3. The evolution of wind power policy in Denmark

Denmark boasts a comparatively long history of wind power development. During both world wars, the nation insulated itself from disruptions to fossil fuel supply lines by generating electricity through wind power. There is an understandable logic behind Denmark's early adopter role in regard to wind power technology—with over 5000 miles of coastline, flat expanses of agricultural land and a blustery North Sea location, Denmark's wind power potential has been likened to that found in the American Great Plains [28].

However post-World War II, the cost of wind power was still too high for utility-scale use and relatively unfettered access to cheap fossil fuel supplies engendered a reliance on imported oil. By 1972, oil constituted a whopping 93% of Denmark's primary energy supply [29]. Consequently, the economic impact of the 1973 Organization of Arab Petroleum Exporting Countries (OAPEC) oil embargo was particularly dire in Denmark.

By 1976, with oil still lurking around the $60 US per barrel level (in 2010 adjusted prices), the Danish government announced a new energy strategy designed to wean the nation from an over-dependence on oil, in part by seeking to exploit Denmark's wind power potential [30]. This marked the beginning of Denmark's modern wind power development program and also represented an early manifestation of a parry and riposte energy policy initiative—mitigating an adverse market development (high price of oil) by a counter-attack strategy (enhance alternative energy capacity). This parry and riposte approach to adapting policy in response to emergent needs would become a common fixture in wind power policy in Denmark.

In support of this new energy strategy, a national wind energy program was created to investigate technological hurdles, encourage the development and field trial of wind power technologies and initiate limited scale consumer adoption. A test center for small wind turbines was established at the Riso National Laboratory for Sustainable Energy (Riso Laboratory) [29]. Funding was also earmarked for the development of two 630 kW turbines and mechanisms were put in place to encourage participation and collaboration between academia, government research centers and some of Denmark's largest manufacturing industries.

By 1979, it became apparent that the government's initial strategy of attracting well-capitalized, private sector champions to drive wind power manufacturing had failed to engender sufficient market interest [31]. Accordingly, the government adopted another parry and riposte strategy—create market demand and in doing so incentivize domestic wind turbine manufacturing. In order to do so, the government announced that wind power projects utilizing wind turbines that were approved by the Riso Laboratory would

Table 1
Principles for developing effective policy amidst complexity.

1. Ensure that policies support a variety of emerging technologies in order to avoid artificially creating winners at the expense of promising emergent technologies.
2. Establish clear and progressive short and medium term targets in order to signal intent to the market.
3. Construct sophisticated environmental monitoring systems in order to highlight unexpected market developments.
4. Establish a malleable policy regime that directly resolves emergent challenges while simultaneously sustaining market momentum to ensure long-term strategies are met.

be eligible for a 30% capital investment tax credit and a tax deduction on the sale of surplus wind energy [32,33].

In retrospect, these financial incentives were insufficient for catalyzing domestic wind power development of any significance; however, the incentives were enough to encourage some of Denmark's larger agricultural equipment firms to dabble in wind turbine R&D. With technical assistance from Riso Laboratories, firms such as Vestas—which started as a blacksmith foundry—began to develop technologically unsophisticated but highly reliable wind turbines that were quality-certified by Riso [32,34].

Due to insufficient domestic demand for wind turbines, it is likely that many of these fledgling wind turbine manufacturers would have curtailed efforts if fate had not intervened. By 1979, California was experiencing a boom in wind power development thanks to passage of a favorable National Energy Act that was supplemented by state-level development incentives [12]. Many of the American wind power manufacturers were focusing on development of high-tech in turbines; and as result, the reliability of these turbines was suspect. Conversely, Denmark's wind turbine manufacturers were building a reputation for producing reliable, quality-certified wind power systems. As result, Danish wind turbines were widely adopted by Californian wind power developers.

Meanwhile, back in Denmark, a second oil crisis and lukewarm response to the government's 1979 development incentives prompted the government to adopt a more strategic approach to domestic market development, commissioning the development of a national wind atlas and regional wind power potential studies in order to better understand market potential. It also established a formal wind power development department at Riso Laboratories to act as a one-stop shop for project developers and host municipalities. Buoyed by a wind power potential study that indicated that wind power in Denmark could generate in the neighborhood of 30 TW hours per year (roughly equal to total electricity consumption at the time), the government was ready to prepare yet another policy parry and riposte to kick-start domestic development.

This time the focus of policy adjustment was on bolstering incentives for wind power investment through a dual track policy approach. The first track aimed to encourage investment by individuals and cooperatives. This entailed a new set of incentives announced in 1984 that included a tax refund of €0.037 per kilowatt hour (kWh), 10-year contracts which fixed the wind power purchase price equal to 85% of the prevailing retail price and a mandate obliging utilities to pay for 35% of all grid connection costs [33,35,36]. In aggregate, these policies amounted to payment to wind power providers of approximately €0.08 per kWh, representing a substantial return on investment [37].

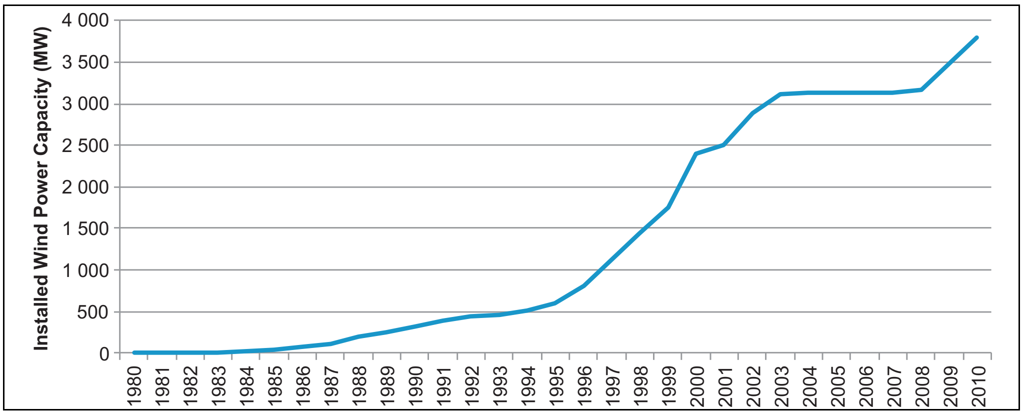
The second track of policy initiatives was designed to encourage the development of wind farms in order to both enhance economies of scale and concentrate wind power installations to attenuate adverse aesthetic impact [38]. These initiatives included a 50% tax rebate on investment capital costs for wind farms [38] and the negotiation of a voluntary agreement with Danish utilities to build 100 MW of wind power capacity between 1986 and 1990 [36]. In combination, these policies launched Denmark's wind power industry (see Table 2) [39].

Policy refinements commencing in 1986 attest to the proactive nature of Denmark's energy policymakers in monitoring market development and responding to emergent needs. First, the government realized that the scale and pace of wind power diffusion in Denmark was going to be insufficient to fill the revenue void that was created for domestic wind turbine manufacturers after policies changed in the United States in 1985, catalyzing a massive contraction in California wind power development. Consequently, with many Danish wind turbine manufacturers teetering on the brink of bankruptcy (including Vestas), the government announced the establishment of a "Wind Turbine Guarantee Company" that guaranteed long-term financing to help Danish firms develop large export projects [32]. Second, in response to market feedback indicating that the 1984 subsidies were sufficient for catalyzing market development, the government acted to rectify its 1979 error of subsidizing investment rather than subsidizing power generation. It announced that the 1979 wind power investment tax credit would be reduced from 20% to 15% in 1986, to 10% in 1987 and finally eliminated altogether in 1989 [35]. Thanks to the healthy subsidies announced in 1984, wind power diffusion continued despite the gradual phase-out of the investment tax credit; and by the end of 1989, Denmark boasted 247 MW of onshore wind power capacity, generating 1.4% of its domestic electricity [39]. On the heels of half a decade of wind power development success, the government published a document in 1990 entitled "Energy 2000", which declared an intention to realize 1500 MW of installed wind power capacity by 2005, sending a strong signal to developers [40].

The emergence of wind power as a commercially viable technology began to engender an unanticipated degree of social dissonance. By 1990, community resistance caused more than 10% of wind power project approvals to be rescinded after public appeals to the Ministry of Environment [41]. The government's policy response was to begin to encourage research into offshore wind power development, culminating in the development of the world's first offshore wind farm in 1991 [42].

Meanwhile, the pace of onshore wind power diffusion was clearly slowing. Between 1991 and 1993, the pace of annual wind power growth declined from 62 MW to 43 MW to 32 MW.

Table 2
Growth of wind power capacity in Denmark.



This was partly due to increased public opposition to wind power [40] and low oil and coal prices. Nevertheless a new policy riposte was required. This came in the form of a new subsidy program, announced in 1992, whereby wind power generators would receive a carbon tax reimbursement of €0.013 per kWh and €0.023 per kWh as a production incentive [43]. In 1993, it commissioned a number of studies to explore the external costs of wind power from a social perspective, an exercise charting conditions for offshore wind turbine installation and a study investigating more effective ways to promote rural wind power development. In May of 1994, the government announced a new wind turbine replacement investment subsidy program offering a tax credit of up to 15% of the original investment for upgrading existing turbines to larger capacity models. These new incentives accelerated the pace of market diffusion. By the end of 1996, Denmark was host to 814 MW of installed wind power capacity, a tenfold increase compared to a decade earlier.

This successful diffusion emboldened the government to reiterate its 2005 target of 1500 MW and prompted the establishment of a new longer-term goal of meeting 50% of Denmark's electricity needs through wind power by 2030. This ambitious market signal fueled a market explosion, wherein 937 MW of new wind power capacity was added by the end of 1999, bringing the total amount of installed wind power capacity to 1743 MW, eclipsing the 2005 target.

In order to ensure that the pace of wind power development would accelerate to meet the lofty goal of providing 50% of Denmark's electricity needs by 2030, the government announced an intermediate target of achieving 20% contribution from renewables by the end of 2003; an ambitious target given that wind power contributed only 8.7% by 1999 and there were no other substantial renewable technologies contributing to electricity generation [35]. In support of this goal, the government announced a new turbine replacement scheme, which guaranteed payment of €0.081 per kWh for qualifying turbine upgrades [44]. This policy ensured that capacity enhancement would start with the least socially invasive projects. Moreover, the government announced a new agreement with Denmark's utilities to install 750 MW of offshore wind turbines before 2008 [43].

In the midst of this positive growth phase for wind power in Denmark, an external challenge arose. A European Union (EU) led initiative to establish an integrated carbon trading market throughout the EU compelled Denmark to announce an intention to replace the successful feed-in tariff approach to wind power development with a carbon trading system that would be phased-in between 2000 and 2003 [45]. Once again, a policy parry and riposte strategy became necessary to ensure that this unanticipated development did not deflate wind power development momentum. Consequently, the government announced that during the transition to the carbon trading system, feed-in tariffs and production incentives would be established and then gradually phased-out. For contracts finalized before 1999, wind power generators would receive a feed-in tariff of €0.044 per kWh and a production incentive of €0.036 per kWh for up to 25,000 full-load hours. Turbines purchased between January 2000 and December 2002 would receive a feed-in tariff of €0.044 per kWh plus a reduced production incentive of €0.013 per kWh (for up to 25,000 full-load hours). Turbines purchased after January 2003 would not be eligible for any subsidies and instead operators would receive market price for electricity generated plus €0.013–€0.036 per kWh under the carbon trading scheme [43].

The transitional nature of these policies proved to be prudent because logistical problems and contentious debate over how the transition should be managed foiled scheduled implementation. Consequently, the government postponed the launch of the carbon trading scheme until January 2002. In the meantime, wind power developers responded to the delay by fast-tracking development plans in order to take advantage of existing incentives. This resulted in a record 637 MW of wind power being added in 2000, bringing total installed capacity up to 2390 MW and elevating wind power's contribution to domestic electricity to 12.1% [39,43].

Events transpiring in 2001 illustrated the capricious nature of policy making in democratic societies. In November 2001, a right-wing Liberal Party/Conservative Peoples Party coalition managed to amass enough seats to form a new government led by PM Anders Forgh Rasmussen. The Rasmussen administration campaigned on a political platform that promised to reign in burgeoning government debt by eliminating excessive expenditure [46]. This gave rise to market concerns that support for the wind power market would be pared back, which catalyzed another surge in development as developers yet again fast-tracked projects to take advantage of existing government subsidies; 387 MW of installed capacity was added in 2002, bringing wind power's share of domestic electricity up to 13.8% [39].

In 2002, apprehension over curtailed support for wind power development was partially validated as the new government moved to cut energy R&D subsidies and reduce feed-in tariffs for wind power. In June 2002, the government announced that plans for the carbon trading program would be shelved and a new pared-down subsidy program would be initiated. Under the new program, wind power generators would sell power to the utilities at the Nordpool spot rate and receive an added premium of €0.013 per kWh. In addition to this subsidy, upgraded turbines would receive a scrap premium of €0.023 per kWh [43].

Critics of these policy changes argue that the Rasmussen administration virtually stopped wind power development in its tracks [35]. On the one hand, there is a degree of statistical support for such a contention. Between 2002 and 2008, only 63 MW of onshore wind power capacity and 209 MW of offshore wind power capacity was added [39]. On the other hand, others have argued that over-subsidization, sub-standard grid interconnectivity and wind power production excesses were producing financially suboptimal results [47] and that a degree of economic rationality needed to be infused into the wind power program to facilitate further expansion.

Regardless of which interpretation one prefers to accept, Denmark's unique political structure ensured that any radical departures from existing policy would be tempered through parliamentary negotiation and compromise. The Danish political system is characterized by a large number of political parties, none of which have managed to claim an absolute majority in Denmark's politics since the beginning of the 20th century. Legislation is typically approved and implemented through political negotiation and compromise, which engenders centrist policy. Consequently, when one coalition government replaces another, there is a high degree of political agreement over policy goals, even if coalitions may disagree over policy design and implementation. This attribute of Danish politics most certainly influenced energy policy under the Rasmussen administration and tempered the implementation of more stringent cut-backs to support programs. Within two years of taking office, the administration partially restored funding to the energy technology program and announced a new offshore wind power development agreement with utilities for two new offshore wind farms of 200 MW capacity each to be installed by 2007 [36,48].

In retrospect, there is evidence to support a contention that the Rasmussen administration's approach to renewable energy development was not antagonistic; but rather, aimed at enhancing economic efficiency. Indeed, the overall contribution of renewable energy to Denmark's electricity supply continued to increase under the Rasmussen administration's policies. This was partly due to enhanced support for fledgling renewable energy technologies. For example, a subsidy was announced for biogas that would provide €0.08 per kWh as a feed-in tariff for 10 years and €0.05 per kWh for the subsequent 10 years. Other subsidies were announced to support "special plants using energy sources or technologies of major importance to the future exploitation of renewable energy" such as wave power, fuel cells, solar energy and biomass [49].

Evidence further suggests that the government was proactively pursuing initiatives designed to attenuate some of the technical barriers to further wind power development. For example, in 2005, the Danish government initiated a major grid restructuring initiative to fulfill terms of a EU directive to liberalize electricity markets in order to support further renewable energy development. East and West transmission networks were merged and placed under the management of a state-owned grid operator, Energinet Danmark. Energinet Danmark was also appointed to oversee operation of the nation's gas network, a technological pairing which provided the technological foundation for attenuating supply fluctuations [50].

Some analysts have pointed out that the Rasmussen administration's wind power subsidies announced in 2002 equalled what would have been provided under later stages of the carbon trading program that was proposed by the preceding Social Democrat—Social Liberal coalition that held power between 1993 and 2001 [43]. Furthermore, new policies that would eventually emerge, commencing in 2007, suggests that the new government was not as opposed to wind power as critics suggested; rather, this period of market stagnation represented a period of technical and financial consolidation designed to enhance the stability of a sector (renewable energy) that it nevertheless supported. Regardless of the interpretation of the Rasmussen Administration's motives for adopting policies that initially quashed wind power development, it was clear by the end of 2006 that something needed to be done to reduce CO_2 emissions in Denmark and position the nation to play a proactive role in EU plans to ramp-up renewable electricity generation capacity.

On 19 January 2007, the government announced a new national energy strategy that signaled the launch of a new policy parry and riposte. Under the proposal, which was agreed to by all the parliamentary parties except the far-left Red-Green Alliance, Denmark would aim to expand renewable energy capacity to satisfy at least 20% of total energy consumption by 2011 and 30% of total energy consumption by 2025 [49]. It was recognized that many of Denmark's turbines were aging and in need of replacement. Consequently, the Rasmussen administration announced a new wind turbine substitution scheme. The goal was to replace approximately 900 turbines (450 kW or less) with 150 to 200 turbines in the 2 MW range [51].

In 2008, the Rasmussen administration announced intentions to foster a 1300 MW increase in wind power capacity by the end of 2012 [52]. According to the plan, 800 MW of this total would come from three new offshore wind parks. To facilitate this increase, an additional "balancing cost" subsidy of €0.03 per kWh was offered on top of the 2002 subsidy of €0.013 per kWh that was tacked on to the Nordpool spot price [49]. Moreover, a compensation package was announced to financially reward communities for hosting onshore wind farms. On top of all this, the government announced that its CO_2 tax would be increased to a level that would equate with the expected price of carbon in 2008-12 (estimated at approximately €20 per ton) and that a new NO_x tax of approximately €670 per metric ton would be introduced from January 1, 2010 [49].

These aggressive policies reinvigorated wind power development. In 2009, 320 MW of new installed wind power capacity was added (238 MW in offshore developments) and in 2010, another 320 MW was added (207 MW in offshore developments). After 178 MW was added in 2011, bringing total installed capacity to 3871 MW, wind power's share of Danish electricity consumption had reached an astonishing 28%.

4. Conclusion

It should be obvious from the historical review of Denmark's wind power development policy that the government was not working from a rigid list of best policy practices. To the contrary, policies emerged and receded, subsidies ebbed and flowed, and even the overall strength of government commitment to market development waxed and waned. This attests to the verity of the premise that technology evolves within a seamless web of social, technological, economic and political influences. These influences give rise to unanticipated stakeholder concerns, competitive responses, technological problems and logistical challenges that demand attention. A standard list of best practices applied uniformly throughout the various phases of a technological transition simply does not have the precision to effectively respond to these emergent demands.

However, it cannot be said that Denmark's wind power development program was entirely unfocused. There is evidence that the four principles for developing effective policy amidst complexity were extant in Denmark's approach to wind power policy development. In terms of the first principle of ensuring that policies support a variety of emerging technologies in order to avoid artificially creating winners at the expense of promising emergent technologies, the RISO laboratories – now called the Risø DTU National Laboratory for Sustainable Energy – that were funded by the Danish government to pursue renewable energy research had and continue to have a broad research remit that includes advancement of many renewable technologies. The biogas, wave power, solar energy and fuel cell subsidies provided by the Rasmussen administration in 2002–03 further serve as evidence that the Danish government was and is diversifying support for renewable technologies.

In terms of the second principle of establishing clear and progressive short and medium term targets in order to signal intent to the market, the government publication "Energy 2000" that was released in 1990 established a target of 1500 MW of wind power capacity by 2005 [40]. In the late 1990s, it reiterated this target and established a longer term goal of 50% renewable energy contribution to the electricity grid by 2030, an initiative largely satisfied through wind power expansion. In 2007, the government announced a goal of meeting 20% of total energy consumption by 2011 and 30% of total energy consumption by 2025 [49]. In 2008, the Rasmussen administration announced wind power-specific targets of fostering a 1300 MW increase by 2012; and in 2012, it announced a plan to meet 50% of Denmark's electricity production through wind power by 2020 and 100% of total energy needs through renewable sources by 2050 [53]. In short, for over two decades, the Danish government demonstrated a progressive commitment to supporting elevated levels of wind power capacity.

In terms of the third principle of constructing sophisticated environmental monitoring systems in order to highlight unexpected market developments, as the previous section described, Danish government initiatives in that regard were exemplary. The Danish wind power development story is marked by examples of integrated technical planning at national, regional and local levels. This allowed the government to carefully track multi-stakeholder responses to policy initiatives. Even the development of Danish wind power systems were marked by advanced collaboration between government, academia and industry that created a foundation for research that was based on emergent market needs.

Finally, in terms of the fourth principle of establishing a malleable policy regime that directly resolves emergent challenges while simultaneously sustaining market momentum to ensure long-term strategies are met, the history of wind power development as documented in the previous section is rife with policy parries and ripostes in response to market dynamics.

There was also a thread of strategic logic that tied the program together. The government's wind power support program began with a set of policy initiatives designed to clarify the technological hurdles associated with wind power diffusion because the program represented more than just a way to enhance domestic energy security; it represented a market opportunity to encourage the proliferation of a technologically savvy industry that complemented the government's industrial development aspirations. The government cobbled together a support package in order to help aspiring firms overcome technological hurdles and field test wind turbines. Once the synergies between industrial development and wind power development became clear, the government then moved to create a domestic market by first, priming the market with initial subsidies in order to test market response and then adjusting policy to regulate the pace of development. As wind power capacity expanded, the government announced development goals and initiated systems to monitor progress. Formative evaluations highlighted emergent challenges – such as addressing social dissonance and the need to encourage more concentrated development – and illuminated policy responses. As economic conditions within the market sector changed, the government responded with adjustments to its subsidies. As targets were met, the government responded with new goals. In short, the basic strategic flow was to nurture technological competence, engender community support, develop new policy to respond to emergent challenges and revise incentives to foster progressive development.

For policymakers in other nations, the history of wind power development in Denmark conveys a very optimistic message, a dedication to progressive development and effective formative evaluation systems that are supported by policy that is responsive to emergent needs can successfully enhance wind power diffusion. Critics might contend that such an approach to wind power development policy (or more broadly to renewable energy development policy) represents an economically suboptimal approach to policy development because it does not establish concrete targets. This might be true in regard to policy formulation in relatively stable environments, but in complex adaptive markets (epitomized by technology policy) where *emergent landscapes* (trends) cannot be adequately predicted due to the complexity of interdependent variables, the best option is to try and anticipate trends while at the same time preparing institutionally to adjust strategy in response to unanticipated developments [6]. Applied back to wind power development policy, establishing program objectives, setting near-term strategic priorities and applying policies that have been proven effective in other nations to address the strategic priorities represent three recursive activities that require adjustment as technological transition progresses and new hurdles emerge. Effective market monitoring and proactive design and timely implementation of parry and riposte policy strategies to counter emergent challenges is the enabling element (and all too often the missing link), which ensures continued stakeholder support necessary for turning policy objectives into achievements.

Clearly, this examination of policy in complex adaptive markets raises more questions than it answers. One question which arises in conjunction with the theme of responsive planning is how does one identify which emergent challenges require a response? Furthermore, what instruments should be applied as the response? For example, the Danish government applied a strategy of coercion in order to encourage utilities to commit to wind farm development. It is unclear whether or not the strategy of encouraging utilities to be involved in the development of wind farms was optimal or even necessary. It is also unclear what impact the coercive approach had on utility commitment toward wind power development. Much more research needs to be done on the strategic application of parry and riposte policy instruments.

Another noteworthy enquiry in relation to improving the effectiveness of parry and riposte policy techniques is whether or not there are strategies which can be strategically applied to mitigate transitional resistance and lock-in transitional pace. For example, in Denmark, social dissonance escalated when the government altered investment incentives to encourage larger wind farm development. It may very well be that a more effectively structured investment subsidy program that better encouraged co-op investment in larger wind farms may have staved off some of the emergent community dissonance. Research into frameworks for improving ex ante predictive accuracy of parry and riposte policies are needed.

Another question that arises around the general theme of progressive policy design is whether or not gradualist policy can adversely affect transition, and if so, under what conditions? One study in regard to energy policy in China concluded that China's gradualist approach to policy development might actually serve as an impediment to developing more effective energy policy [22]. Yet, the premise of this paper is that incrementalism is an essential aspect of effective renewable energy policy because of the complex, adaptive nature of energy markets. The argument posed in this paper makes more intuitive sense and is valid in the case of Denmark; however, one envisions that there may be nations where political ideology is so severely fractured that the slower developmental pace associated with gradualist policy would increase the possibility that political change could result in transitional policy being derailed by an in-coming party that opposes renewable energy development.

Although these are all valid questions that stem from the discourse in this paper, it is unlikely that ensuing research would invalidate the defining premise of this paper that technological change is a dynamic process which is complicated by the progressive evolution of technological development, unanticipated stakeholder responses and a host of emergent challenges. It is a murky world dominated by uncertainty and unanticipated change. Nevertheless, the presence of high levels of uncertainty should not imply that "no plan" is the best plan. Rather, successful governance of technological evolution requires policies that foster competition on a level playing field, a consistent end-vision, advanced monitoring systems to track market dynamics and malleable policy responses to mitigate emergent barriers to development. As Joseph Schumpter observed in describing the evolution within complex systems, "since we are dealing with a process whose every element takes considerable time in revealing its true features and ultimate effects… we must judge its performance over time, as it unfolds through decades or centuries" [1]. In Denmark's case, it appears that enough time has passed to conclude that the nation's complex adaptive markets approach to wind power development policy holds merit that warrants further investigation by policy theorists.

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References

[1] Schumpter JA. Capitalism, socialism and democracy. Milton Park, UK: Routledge; 2010/1943.
[2] Rogers EM. Diffusion of innovations. USA: The Free Press; 1995.
[3] Hughes TP. Networks of power: electrification in western society 1880–1930. Baltimore, USA: Johns Hopkins University Press; 1983.
[4] Axelrod R, Cohen MD. Harnessing complexity: organizational implications of a scientific frontier. USA: The Free Press; 1990.
[5] Brown SL, Eisenhardt KM. Competing on the edge: strategy as structured chaos. USA: Harvard Business School Press; 1998.
[6] Beinhocker E. Robust adaptive strategies. Sloan Management Review 1999;4: 95–106.
[7] IPCC. Climate Change 2007. Synthesis report. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC); 2007.
[8] Stern N. The global climate change imperative. Business Week 2007:90.
[9] David PA. Clio and the economics of Qwerty. American Economic Reviews 1985;75:332–7.
[10] Friedman M. Capitalism and freedom. Chicago, IL, USA: The University of Chicago Press; 2002/1962.
[11] Komor P. Renewable energy policy. USA: iUniverse; 2004.
[12] Mallon K. Renewable energy policy and politics: a handbook for decision making. UK: Earthscan; 2006.
[13] Capoor K, Ambrosi P. State and trends of the carbon market 2008. Washington, DC, USA: World Bank; 2008.
[14] Valentine SV. Braking wind in Australia: a critical evaluation of the renewable energy target. Energy Policy 2010;38:3668–75.
[15] Mendonca M, Jacobs D, Sovacool B. Powering the green economy: the feed-in tariff handbook. Oxford, UK: Earthscan; 2009.
[16] Chai Q, Zhang X. Technologies and policies for the transition to a sustainable energy system in china. Energy 2010;35:3995–4002.
[17] Chang Y-C, Wang N. Environmental regulations and emissions trading in China. Energy Policy 2010;38:3356–64.
[18] Farrell D, Bozon I. Demand-side economics: the case for a new US Energy Policy direction. In: Campbell KM, Price J, editors. The Global Politics of Energy. USA: The Aspen Institute; 2008. p. 45–61.
[19] Hansen J. Storms of my grandchildren. London, UK: Bloomsbury Press; 2009.
[20] Valentine SV. Toward the Sino-American Trade Organization for the Prevention of Climate Change (STOP-CC). The Chinese Journal of International Politics 2011;4:447–74.
[21] Jamasb T, Pollitt M. Incentive regulation of electricity distribution networks: lessons of experience from Britain. Energy Policy 2007;35:6163–87.
[22] García C. Grid-connected renewable energy in China: policies and institutions under gradualism, developmentalism, and socialism. Energy Policy 2011;39:8046–50.
[23] Qiang W. Effective policies for renewable energy—the example of China's wind power—lessons for China's photovoltaic power. Renewable and Sustainable Energy Reviews 2010;14:702–12.
[24] Valentine SV. Disputed wind directions: reinvigorating wind power development in Taiwan. Energy for Sustainable Development 2010;14:22–34.
[25] Valentine SV. Japanese wind energy development policy: Grand plan or group think? Energy Policy 2011;39:6842–54.
[26] Tsai SD, Chiang H-q, Valentine S. An integrated model for strategic management in dynamic industries: qualitative research from Taiwan's passive-component industry. Emergence 2003;5:34–56.
[27] Barney JB. Looking inside for competitive advantage. The Academy of Management Executive 1995;9:49–61.
[28] Gipe P. Wind energy comes of age: California and Denmark. Energy Policy 1991;19:756–67.
[29] Carlman I. Wind power in Denmark! Wind power in Sweden? Journal of Wind Engineering and Industrial Aerodynamics 1988;27:337–45.
[30] Meyer NI. Renewable energy policy in Denmark. Energy for Sustainable Development 2004;8:25–35.
[31] Kamp LM. Wind turbine development 1973–2000: a critique of the differences in policies between the Netherlands and Denmark. Wind Engineering 2004;28:341–54.
[32] Kamp LM. Danish and Dutch wind energy policy 1970–2000: lessons for the future. International Journal of Environment and Sustainable Development 2006;5:213–20.
[33] Kristinsson K, Rao R. Interactive learning or technology transfer as a way to catch-up? Analysing the wind energy industry in Denmark and India Industry and Innovation 2008;15:297–320.
[34] Wüstenhagen R. Sustainability and competitiveness in the renewable energy sector: the case of Vestas wind systems. Greener Management International 2003:105–15.
[35] Buen J. Danish and Norwegian wind industry: the relationship between policy instruments, innovation and diffusion. Energy Policy 2006;34: 3887–97.
[36] Meyer NI. Development of Danish wind power market. Energy and Environment 2004;15:657–73.
[37] Morthorst PE. Capacity development and profitability of wind turbines. Energy Policy 1999;27:779–87.
[38] Madsen BT. Windfarming in Denmark. Journal of Wind Engineering and Industrial Aerodynamics 1988;27:347–58.
[39] Danish Energy Agency. Annual Energy Statstics 2010. Copenhagen, Denmark: Danish Energy Agency; 2011.
[40] Danielsen O. Large-scale wind power in Denmark. Land Use Policy 1995;12:60–2.
[41] Christensen P, Lund H. Conflicting views of sustainability: the case of wind power and nature conservation in Denmark. European Environment 1998;8: 1–6.
[42] Breton SP, Moe G. Status, plans and technologies for offshore wind turbines in Europe and North America. Renewable Energy 2009;34:646–54.
[43] Agnolucci P. Wind electricity in Denmark: a survey of policies, their effectiveness and factors motivating their introduction. Renewable and Sustainable Energy Reviews 2007;11:951–63.
[44] Meyer NI, Koefoed AL. Danish energy reform: policy implications for renewables. Energy Policy 2003;31:597–607.
[45] Morthorst PE. The development of a green certificate market. Energy Policy 2000;28:1085–94.
[46] Hvelplund F. Renewable energy and the need for local energy markets. Energy 2006;31:2293–302.
[47] Lund H, Münster E. Integrated energy systems and local energy markets. Energy Policy 2006;34:1152–60.
[48] Rasmussen F, Madsen PH. Current direction of danish wind energy research—the researchers point of view. Journal of Solar Energy Engineering, Transactions of the ASME 2004;126:1105–9.
[49] European Renewable Energy Council. Renewable Energy Policy Review: Denmark. RES 2020: Monitoring and Evaluation of the RES Directives implementation in EU27 and policy recommendations to 2020. Brussels, Belgium: European Renewable Energy Council; 2009.
[50] Mignard D, Harrison GP, Pritchard CL. Contribution of wind power and CHP to exports from Western Denmark during 2000–2004. Renewable Energy 2007;32:2516–28.
[51] Ladenburg J. Attitudes towards on-land and offshore wind power development in Denmark; choice of development strategy. Renewable Energy 2008;33:111–8.
[52] Ekman CK, Jensen SH. Prospects for large scale electricity storage in Denmark. Energy Conversion and Management 2010;51:1140–7.
[53] Danish Energy Agency. Energy Policy Report 2012. Copenhagen, Denmark: Ministry of Climate, Energy and Building; 2012.