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Diffusion of Innovation System Elements

A Novel Method to Study Technology Development and Its Application to Wind Power

Master of Science Thesis in the Master Degree Programme, Industrial Ecology

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Abstract

A method for the quantitative study of complex technological innovation systems is outlined, coupling the systems-based thinking of previous studies with quantitative methods from diffusion studies. Through a case study involving the global wind power technological innovation system, the hypothesis-testing capabilities of this method are shown.

First, it is shown that the method can help elucidate the nature of relationships between innovation system components in quantitative terms. In the case study, the strongest correlation is found between R&D funding (corresponding to system elements Resource Mobilization, Science/Knowledge Development, and Guidance of Search) and publication of scholarly articles (corresponding to system elements Knowledge Development, Knowledge Diffusion, and Science). The weakest correlative relationship seen is between R&D expenditures and founding of wind turbine manufacturers (corresponding to system elements Entrepreneurial Activity, Industry, Actors, Infrastructure, Resource Mobilization, and Markets/user practices).

Additionally, the ability to gauge the value of innovation activities in terms of successful technical development and deployment is demonstrated, revealing some evidence that more innovative nations have more successfully deployed wind power technology. The data suggest that innovation in the establishment of national policies is the strongest predictor of successful technical deployment, followed by innovation in the founding of national industry associations. When the system goal is building of a competitive domestic industry, innovativeness in firm entry is the strongest predictor, followed by that of national policy development.

Finally, the timing of various system development events is compared across the countries in the data set to show the method's ability to identify plausible causal chains. In the wind power case, some general conclusions of a linear model of technical development are supported, namely, that R&D funding tends to precede scientific publication and that these two tend to come before firm entry, foundation of industry associations, and national policies. However, for these remaining categories, the data supports more complex causal relationships, such as feedback loops.

Keywords: Technology diffusion; Technological Innovation Sytems; Wind power

Contents

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1 Introduction

The global energy transformation system as it exists today is decidedly unsustainable. Limited availability of fossil fuels presents one challenge, but another, likely more pressing problem, is that of climate change caused by anthropogenic emissions of carbon dioxide and other greenhouse gases. This situation creates an imperative for massive change in the technological systems used to provide the globe with readily available energy in useful forms [Smil, 2003].

Understanding the scale of such a change necessitates looking beyond the simple replacement of fossil fuel based power plants with more environmentally friendly solutions. The energy system is a truly massive socio-technical system, including not simply physical components like power plants, electric power lines, substations, and other infrastructure, but also strong links to myriad other related industries, from mining to design and manufacturing of durable household goods [Smil, 2003]. At the same time, this system of interconnected technologies is accompanied by the software of knowledge, legal systems, and expectations which are created and maintained through networks of social groups, such as technology users, lobbies, academic communities, and others. The combination of large scale and high degree of connectivity within this system gives it the property of strong resistance to fundamental change, creating a state of so-called technical lock-in. It is within this context that new energy technologies must develop and grow in order to address the current system's sustainability shortcomings [Grübler, 1998].

Previous studies on the growth of new technologies within this context have tended to fall into one of two categories. The first focuses on quantitative data on the diffusion of the technology, often accompanied by short-term forecasts of how the technology will grow. The second focuses on the high complexity and interconnectedness of the socio-technical system to develop qualitative models for understanding its behavior and make recommendations based on this understanding for policy intervention or other aspects of development strategy. This leaves an interesting and under-explored area of research, combining the quantitative nature of diffusion studies with the systems-thinking approach found in the more qualitative studies. Work in this area might elucidate a deeper understanding of the relationships between components of complex socio-technical systems than is provided in diffusion studies, while also facilitating reproducibility, generalizability, and hypothesis testing capabilities not present in qualitative system studies.

2 Theory and Literature Review

This study draws principally on past work in two rather different research traditions. The first is technology diffusion or diffusion of innovations, dealing with the spread and adoption of new ideas or technologies, generally with some focus on predictive modeling. The second can be broadly termed as innovation studies or technical change studies. The focus here has tended to be on the development of conceptual frameworks for the framing of historical examples of technological change and innovation system developments.

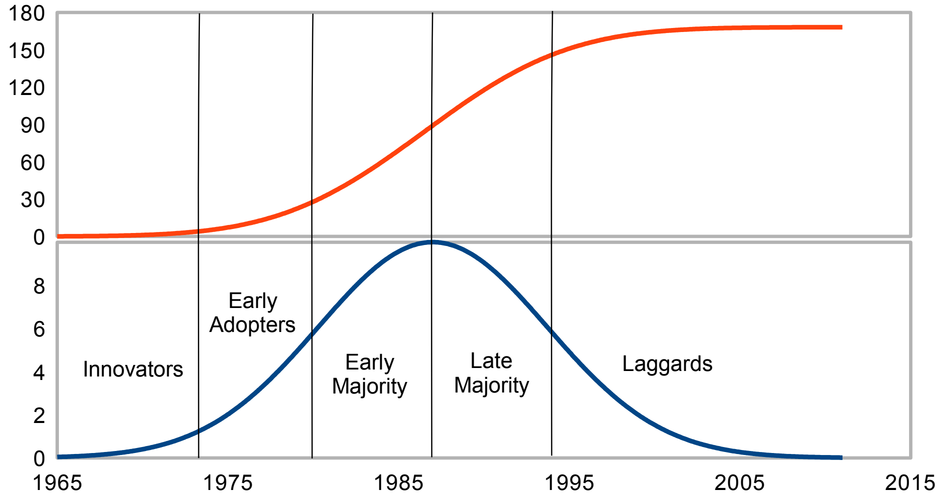
2.1 Diffusion Studies

Research into the diffusion of innovations is historically rooted in several different disciplines, including anthropology, sociology, education, industrial engineering, and advertising. In these different fields, the focal points and specific research questions have varied. For example, anthropological studies have often looked mostly at the changes induced in a society after the introduction of a new technology, while industry-sponsored studies have tended to look at such questions as how advertising can influence adoption of a new product or how to optimize scale-up activities to accommodate an expected diffusion pattern [Rogers, 1962]. One common point among these varied studies, however, is the recognition of the S-shaped curve for adoption of a new technology or innovation [Kemp and Volpi, 2008].

This characteristic curve, generally plotted as cumulative adoption on the y-axis versus time on the x-axis, traces a pattern of slow growth early on, but with an increasing rate of change, followed by a decreasing rate of change until the curve levels off at some saturation value. Historical case studies show that this behavior is generally in line with actual experience in the spread of new technologies [Grübler, 1998]. An example can be seen in Figure 1.

The underlying phenomena to explain this behavior vary among researchers and academic disciplines [Geroski, 2000]. The two extreme views can be described as social pressure-driven and individual variety-driven. The first view suggests that the driving force for adoption of an innovation is the slow shift in social pressure as more and more individuals adopt until eventually everyone sees the innovation as the new norm. In this view, the S-curve of adoption of a new technology arises from a combination of the time it takes for individuals to be made aware of a new technology and the manner in which individuals respond with different strength to the adoption of the technology among their peers. Those who adopt early in the curve are generally aware of the existence of the technology earlier and are less reliant on the approval of their peers in making their adoption decisions. The second view, on the other hand, suggests that individual decisions on whether or not to adopt an innovation will be dependent on individual cir-

Figure 1: Stylized S-curve of cumulative diffusion (top half) and Gaussian of period addition (bottom half) (adapted from Meade and Islam [2006]). Vertical lines and labels show the adopter groupings developed by Rogers [1962].



cumstances, such as the perceived value to be derived from the innovation, size of operation (in the case of companies or farms), access to income, or age of current equipment (in the case of replacement technologies). In reality, it is likely that some combination of these two ideas is at work in most diffusion processes.

Research efforts have included extending these models to capture more of the complexity in real systems in which innovation is embedded. For example, topics such as supply-constrained diffusion [Ho et al., 2002], serial diffusion of multiple generations of a technology, generalized models to capture external shocks to the system [Valle and Furlan, 2011], and coupling learning phenomena with standard diffusion models have all been explored in the literature [Bass, 1980]. There is, however, debate about whether more complex models give greater precision, and whether this is worth the increased difficulty in using the model that accompanies increased complexity [Makridakis and Hibon, 2000].

Another research activity within the field of diffusion of innovations has been studying what systematic differences exist between those who adopt earlier compared to later than average. Individuals can be placed into adopter categories, based on how far in timing the adoption occurs before or after the average time of adoption, and then additional variables can be measured for correlation to adoption timing. A standard method of breaking the curve into five adopter categories, as developed by Rogers [1962] can be seen in Figure 1.

2.2 Technological Innovation Studies

Another approach to understanding the processes involved in the development and deployment of new technologies in society can be found in the field of innovation studies. Here, mostly qualitative models have been developed to describe overarching processes behind radical technological change, and at a more focused level, behind the development of innovation systems surrounding a new technology. Many studies have been historical in nature, giving something of a narrative to past cases in which new technologies have moved from niche applications to a dominant position, often replacing an older technical solution in the process. In pursuing this case study approach, the researchers are able to give a more concrete picture of the application of otherwise abstract ideas about the development and spread of a technology. However, this narrative style also tends to preclude clear and simple comparisons of model applicability to different technologies.

Multi-level perspective. One common qualitative model for technical change is the Multi-Level Perspective (MLP) [Geels, 2002]. The overall socio-technical system is subdivided into a hierarchical system containing the niche region, the technology regime, and the landscape. Circumstances of technical change are explained based on interactions between these levels.

As an example, one series of interactions this model might highlight as leading to technical change is as follows: Niche markets for a new technology slowly grow and combine with one another to give a dominant design and direction of progress for the technology. It forms a complex system that mimics that of the dominant incumbent system, only at a much smaller scale, and it is unable to grow any further due to incompatibilities with the dominant system. A sudden shift at the landscape level, such as a disaster that highlights previously unrecognized shortcomings of the dominant system, changes public sentiment and creates an opportunity for the new technology to break through and either take over or meld with the dominant system.

This very generalized narrative gives a sense of how MLP can be (and has been) used. Its main strength lies in its open-ended nature, which facilitates the mapping of circumstances in vastly different technologies to an overall "structure of the change process". In this way, the term framework theory can be taken quite literally, as the open structure acts as a frame on which more specific elements from a technological system can be hung during application, to give a birds-eye view of the technical change process.

Technological innovation systems. A related approach, with a somewhat different focus, studies what is called the technological innovation system (TIS). In this case, the system to be studied is envisioned as a collection of components with an overarching goal of advancing and propagating a technology. System components include actors, networks, institutions, and (in some interpretations) the technology itself. While the embeddedness of this system in a larger ecosystem dominated by some incumbent technology is recognized, it is less in focus for TIS than it is for MLP.

System performance is analyzed based on what are termed system functions, or key activities carried out in the process of pursuing the overarching goal [Hekkert et al., 2007, Bergek et al., 2008]. As an example, a few proposed system functions include knowledge development and diffusion, market formation, and resource mobilization. The degree to which these functions are carried out at various times in the development of the technology give rise to a shifting set of functional patterns during the technology's lifetime. By looking for incompatibilities between the functional pattern and the needs of the technology, recommendations can be made for targeted policy intervention.

Applications of TIS have tended to look at one technology at the regional or national level. Functional analyses are based on a combination of semi-quantitative data about the system and interviews with individual experts in the field. This might include industry actors, politicians, or academics in the nation or municipality in which the technology is being studied. Jacobsson and Bergek [2004] used the framework to then identify blocking mechanisms for system development and to compare development paths in different countries in Europe. Bergek et al. [2008] explored historical cases of renewable energy technological innovation systems in order to identify interactions between system functions. Other goals of past studies include providing explanations for variable degrees of system success through comparative analyses, and providing recommendations for targeted policy intervention [Negro et al., 2007, Jacobsson and Bergek, 2011].

TIS: Unresolved issues. TIS advocates a functional assessment in order to gain a deeper insight into the workings of the system under study. The argument is that structure alone is unsatisfactory because it is difficult to judge the goodness of a given system structure. Specifically, a structure that is appropriate and yields success in one system might inhibit development in another. This is the reason for the creation of a list of system functions in TIS studies, used in a process to identify what are termed functional patterns.

Upon closer inspection, there appears to be some degree of circularity to this approach. While it seems logical to study system functions in order to identify weaknesses in system performance, many descriptions of functional fulfilment seem to fall back onto descriptions of structural elements. For example, a researcher might point to a large number of market entrants in a given time period and suggest that this gave greater legitimacy to the technology.

From the other direction, if one wants to identify the degree of fulfilment of the function called direction of search, one might measure the number of companies founded. When this is high, it would seem direction of search is being effectively met, since new actors are being drawn to the appeal of the technology enough to enter the market.

This apparent link between structure and function should not be surprising. The "Form follows function" mantra has thematic significance in fields as diverse as biology, materials science, architecture and design, and media studies (the media is the message). One key question is, which structural characteristics are important at a given time or to answer a given question about the technology?

Summary. In each of these approaches, a somewhat stylized conceptual model for a technology and its societal context is described. Most often, the application of this model is performed in a case study approach, and the value of these studies have been twofold. First, they provide interesting historical lessons about how technologies have come to be dominant or fallen out of favor over time and, in doing so, give clarity to the embedded nature of technologies in societal systems. Second, they present reasonable tools for envisioning potential routes to large scale technical change, as well as barriers to the large scale deployment of a young technology.

Few attempts have been made to unite the quantitative nature of innovation diffusion research to the holistic approach found in innovation studies. The closest thread of research is the history event analysis used in, for example, Negro et al. [2007].

3 Purpose, Objective, and Scope

The central purpose of this work is to develop a novel quantitative method for studying the dynamics of socio-technical systems by drawing on elements of technology diffusion studies. Namely, the approach will use quantitative diffusion curves to map changes in technical innovation system elements which have been identified in past research in innovation studies.

The objective of this work is to specify this quantitative method in general enough terms for other researchers to use it, while also giving an example of its use to study the diffusion of the global wind power technological innovation system to date. From the specific example of this system, the nature of interactions between the various elements over time will be explored, and the ability of the method to test hypotheses and reveal otherwise unseen patterns in the growth of the technology will be tested.

The scope of the current work includes the method's specification and application to the study of modern wind power technology. In keeping with the holistic approach found in the field of innovation studies, the wind power technology system is broadly defined to include both the hardware elements (i.e. the physical machines and devices used to harvest wind power), those elements from connected technology systems (i.e. the electricity network infrastructure to which wind turbines are connected in order to provide useful electricity to consumers), and the software elements of the technology (i.e. rules, regulations, and norms associated with the technology).

Due to the nature of the purpose set forth above, the structure of the work which follows is somewhat unorthodox. Rather than having a formal Methods section followed by a Results section, the description of the method employed (and developed herein) is broken into steps. Each step will contain information about how the work was performed, as a traditional Methods section might, followed directly by an illustration of its use in the wind power case study which was carried out. As the development of the method used is the central outcome of the study, it is hoped this structure avoids potential confusion.

4 Method Description and Illustrations

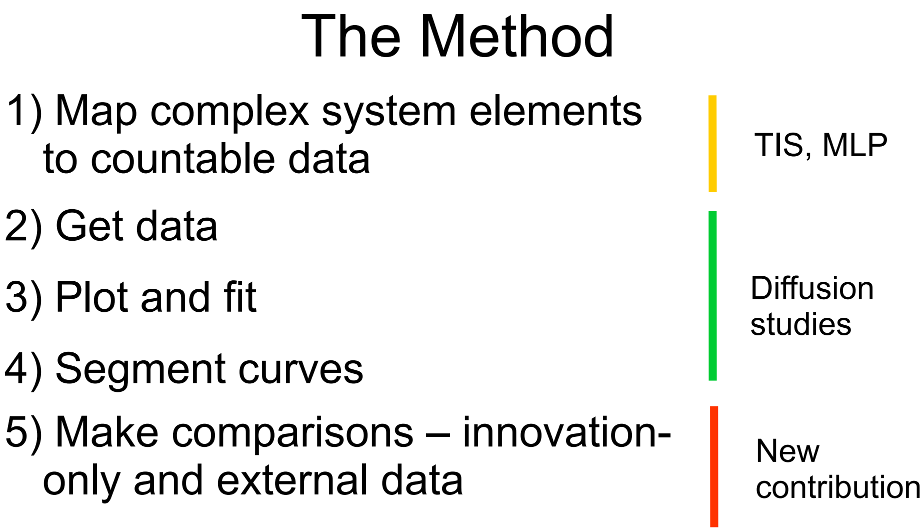
A rough overview of the method developed and employed in this work is shown in Figure 2. The background on which each step draws most heavily is shown to the right of the figure. The sections that follow proceed through these steps in much greater detail.

4.1 Mapping system elements to quantifiable data sets

As described above, the point of departure for the proposed method is complex system models from innovation and technological change studies. Prior research in these disciplines has proposed various lists of important system components and functions in technology development. Some of these components are included in the rectangles pictured in Figure 3. Namely, a list of seven system functions from TIS [Hekkert et al., 2007], the four broad system components commonly used in TIS [Jacobsson and Bergek, 2011], and a list of seven system components commonly found in MLP are included [Geels, 2002]. These system elements are subsequently connected to a series of quantifiable data sets, shown in the ovals in the center of the figure.

These mappings should not be considered comprehensive. To take one example, the system function Entrepreneurial Activity has been mapped to data sets for number of manufacturers and number of patents. The idea is that manufacturing firms are founded when entrepreneurs choose to dedicate their efforts to developing the technology or some new value proposition to

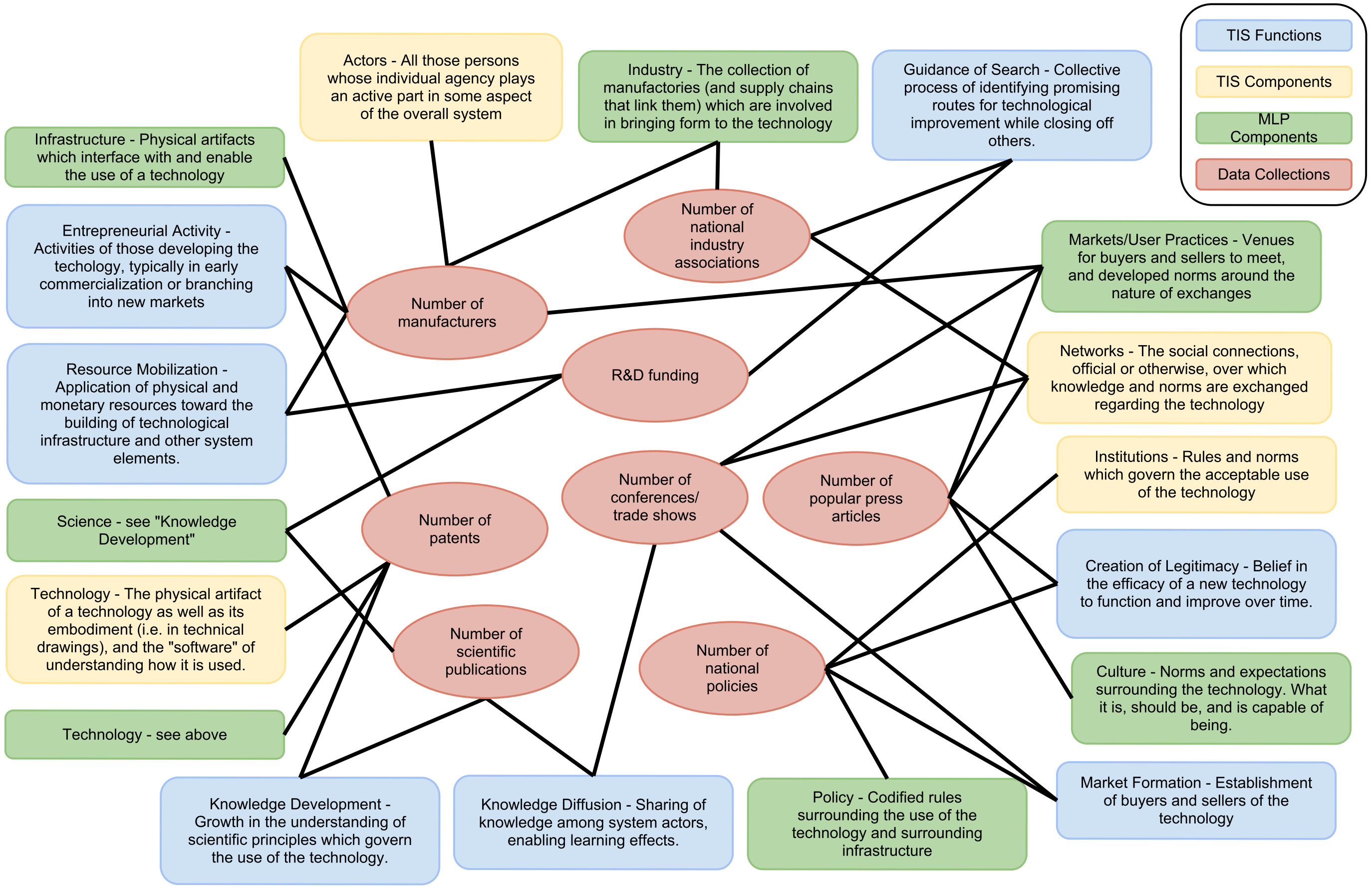
Figure 2: Overview of the method developed and employed in this thesis — The steps are connected to the theoretical background on which they primarily draw to the right



bring the technology to a new or wider market. At the same time, these entrepreneurs might seek patent protection for their novel ideas, hoping to leverage their intellectual property to build successful companies. One could certainly imagine additional data metrics that might reflect Entrepreneurial Activity, for example, the sum total of venture capital funding going into start-ups related to the technology (also clearly an example of Resource Mobilization). This limit in scope of the current mapping is true for most of the system elements listed, as they are often expansive, complex concepts which are difficult to fully capture.

The selection of data sets, shown in the red ovals in Figure 3, is a product of the interface of brainstorming and pragmatism. Issues of data availability and simplicity of interpretation helped pare down from a larger list to the one presented here. As this represents an early attempt at performing this translation, more work and discussion among researchers is necessary to truly assess the most appropriate data sets to use. Additionally, it should be remembered that this list might be somewhat technology specific, and even shift over time as a technology develops. This leaves quite a lot of space for interpretation and subjective assessment by the practitioner applying this method.

Figure 3: Proposed mapping of innovation system elements to data sets



4.2 Data collections

Number of manufacturers. Publicly available lists of wind turbine manufacturers were aggregated and dates of entry into the market were found, primarily through company websites. Where a clear distinction was possible, manufacturers of small home-installation turbines were not included, in order to focus on industrial-scale applications. Depending on the individual circumstances of the company, entry into the market could mean founding date (for companies solely working on wind power technologies) or date of diversification into wind power technology. These results were aggregated to establish a data series of number of firms on the market as a function of time. In total, the sample includes 51 companies in 20 countries.

Number of scientific publications. Scopus, a commercial database of scientific publication titles and abstracts, was queried with search terms associated with wind power or wind machines used for the generation of electricity. Additionally, background samples of common scientific terms (theory, method, and trend) were used to correct for the background trend of an increase in overall scientific publications from 1970 to today. Search results were tabulated by publication year from 1966 to 2011. In addition, this dataset was broken down to identify time of entry at the country level, by finding the earliest author included in the dataset affiliated with a given country.

Number of popular press articles. Google News Archive, a publicly available internet news aggregator, was queried with search terms associated with wind power or wind machines used for the generation of electricity. Additionally, a background sample of common news topics was queried to provide a measure of available news sample size in each year. This was necessary because the total number of news sources and articles covered sharply rose after about the year 2000, leading to a bias in the search results. Search results were tabulated by publication year between 1970 and 2011, and were scaled by year based on the background search results.

Number of patents. An online tool for the United States Patent and Trade Office (USPTO) was used to search patent titles for references to wind turbines or wind machines. These results were tabulated on an annual basis from 1976 to 2011.

Number of national policies. For as many countries as possible, the earliest national policy dealing explicitly with wind power, beyond basic research and development financing, was identified. This could be anything from equipment reliability standards to feed-in tariffs to quantified installation targets in a national energy roadmap. As a starting point, the

Table 1: Dataset details summarized

Dataset	Start Date	End Date	Number	Principal Source
Number of manufacturers	1974	2009	50	Company websites
Number of scientific publications	1970	2011	20264	Scopus
Number of popular press articles	1970	2011	35345	Google News Archive
Number of patents	1976	2011	1034	USPTO Archive
Number of national policies	1978	2011	66	International Energy Agency, web search
Number of national industry associations	1974	2011	43	Industry/trade group websites, web search
Research and development funding	1974	2010	28 (countries)	International Energy Agency
Number of conferences/trade shows	1989	2011	72	Industry/trade group websites, web search

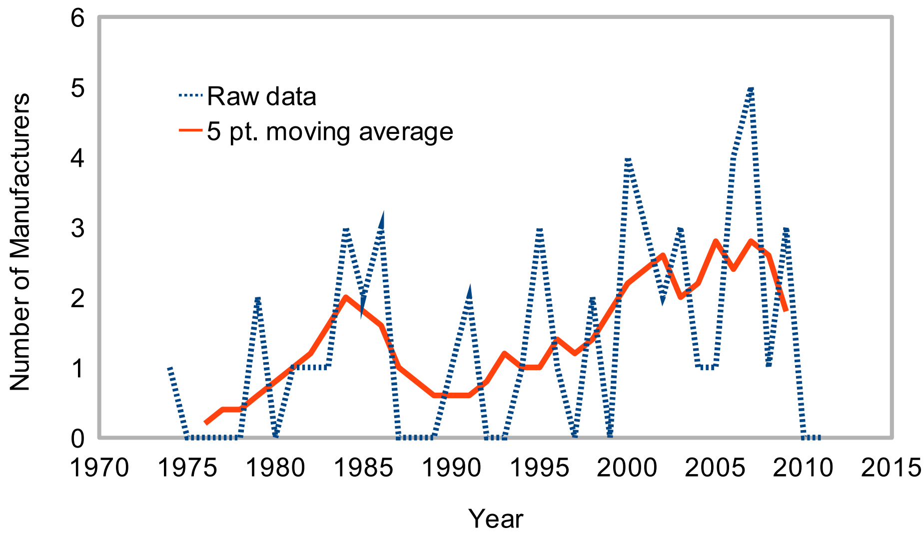
International Energy Agencys Global Renewable Energy Policies and Measures Database was used. For those countries with no relevant entries in the database, subsequent internet searches were carried out, frequently leading to information on renewable or wind power advocacy group websites. Overall results were tabulated on an annual basis, spanning from 1978 to 2011. The sample includes 66 countries.

Number of national industry associations. For as many countries as possible, the founding date of the earliest national wind power association was identified. Information was taken in the majority of cases from association websites, although in some cases, personal correspondence was used. Results were tabulated on an annual basis, spanning from 1974 – 2011. The sample includes 43 countries.

Research and development funding Data was taken from the International Energy Agency, identifying R&D funding in inflation adjusted USD for wind power technology at the national level for 28 countries from 1974 to 2010.

Number of conferences/tradeshows A list of internationally attended wind power conferences, workshops, and trade shows was compiled, primarily from trade organization website archives. The list spans the years 1989-2011 and includes 72 events in 25 countries.

Figure 4: Five-point centered moving average applied to raw data on number of manufacturers founded, revealing a bi-modal trend



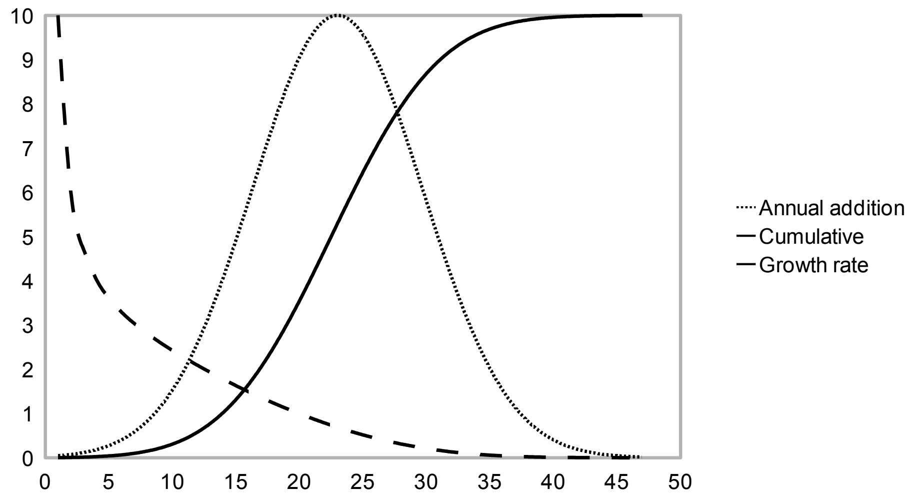
4.3 Data plots

Collected data are plotted below in three forms for each category highlighted in Figure 3. First, non-cumulative data show new additions by year for each category. From a theoretical perspective, these non-cumulative curves would trace a Gaussian (bell-shaped) curve in an idealized diffusion case. In several cases, a small total number of data points gives rise to very noisy curves from which it is difficult to see long term trends. In these cases, a 5-point centered moving average smoothing filter was applied to reduce the effects of sharp changes in value and highlight long-term data trends. An example of the application of this filter is shown in Figure 4.

Second, cumulative plots show the total value for each category as a function of time. This is obtained by a simple summation of all values on the non-cumulative curve prior to a given point in time. From a theoretical standpoint, these curves should trace the characteristic S-shaped diffusion curve.

Finally, cumulative data are plotted as annual year-on-year growth rates. This can reveal some details which are otherwise obscured by the scaling of particularly high valued cumulative curves, such as early fluctuations in growth or later surges in growth rate. This is most obvious in the case of the cumulative installed wind power capacity where details in early growth are not very visible. In the idealized case, this type of curve would trace an exponential decay approaching zero at large time values.

Figure 5: Expected shape for three methods of plotting ideal diffusion curve data



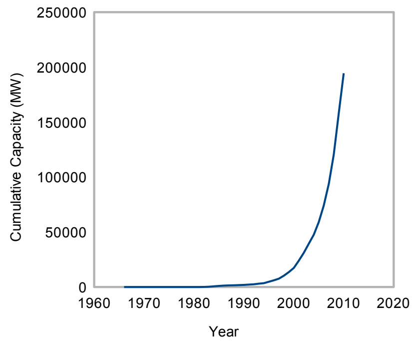
A chart showing the expected shapes of these curves in the ideal diffusion case is shown in Figure 5. The actual values are not important, as all three curves have been scaled to simply show the general shape they should take.

Cumulative installed capacity. All the data categories should theoretically have a connection to the final outcome of total deployment of wind power capacity around the globe. This data can be seen in Figure 6. The curves show general agreement with the idealized shapes of their counterparts in Figure 5, only at an incomplete stage. The S-curve (Figure 6a) is still in its sharp increase and has not yet reached its point of inflection, while the Gaussian (Figure 6b) is still tracing its leading edge and has not yet peaked. The growth rate over time shows some departure from ideality, with small peaks present between years 1995 and 2002, signifying a sudden surge in growth of deployed wind power during those years.

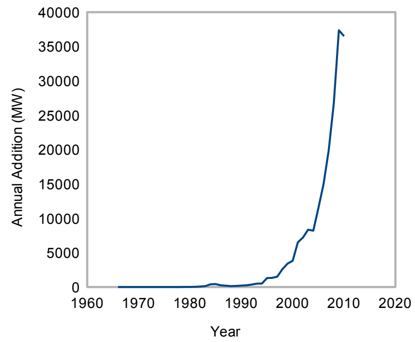
Number of manufacturers. The data on number of wind turbine manufacturers over time are shown in Figure 7. Here, there are a few clear departures from ideal behavior. The most obvious difference can be seen in the annual additions (Figure 7b) where a distinctly bimodal shape arises, rather than the ideal Gaussian distribution expected. One way to treat this is to think about the data as reflecting two separate diffusion events, one spanning from approximately 1976 to 1990, and the other from 1991 to today. This can also be seen in the short plateau in the cumulative curve

Figure 6: Global installed wind power capacity

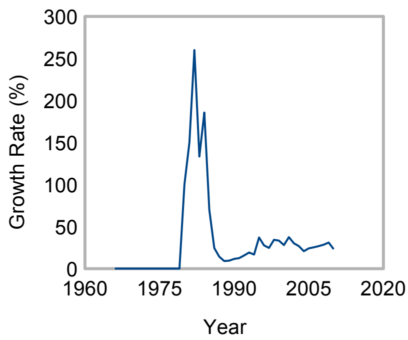
(a) Cumulative



(b) Annual Addition



(c) Growth Rate

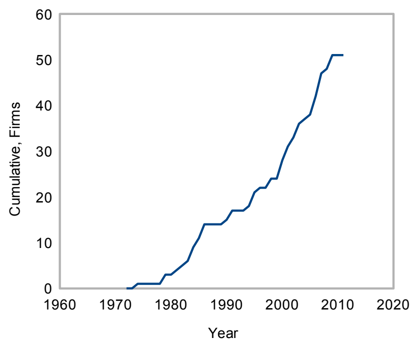


(Figure 7a) around 1990. The growth rate curve shows some choppy behaviour, even after a smoothing filter was applied. This is related to the small number of data points, making the discrete nature of the addition of each new company apparent.

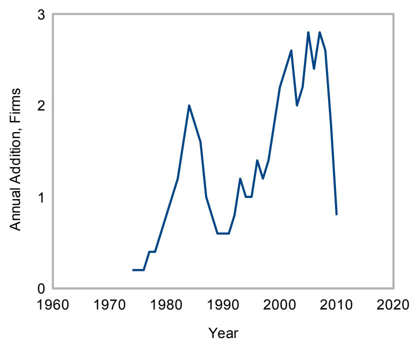
In terms of data quality, there are some key points to remember for this data category. First, only turbine manufacturers are included, which represents only one step in the overall value chain associated with wind power. Companies behind the financing, ownership of wind parks, and component manufacture are equally important to the overall system and represent other aspects of entrepreneurial activity. Second, there is a distinct selection bias in the data set, arising from the fact that the information was collected in 2011–12, almost entirely by means of internet searches. What this means for the data is that it will generally fail to capture firms which were founded and subsequently failed since they likely lack an internet presence.

Figure 7: Number of wind turbine manufacturers

(a) Cumulative



(b) Annual Addition (Moving average filter applied)



(c) Growth Rate (Moving average filter applied)

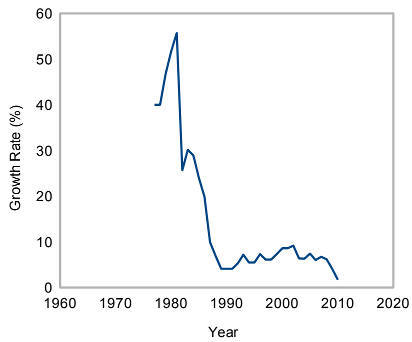
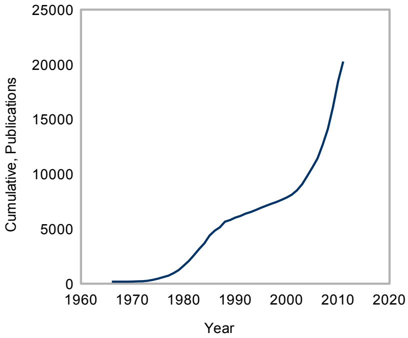
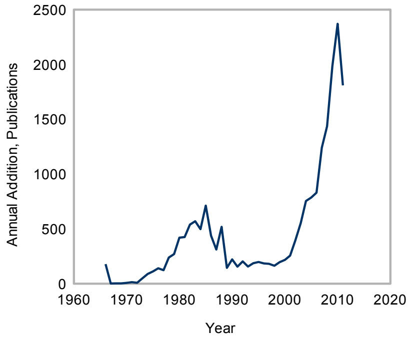


Figure 8: Scientific publications related to wind power

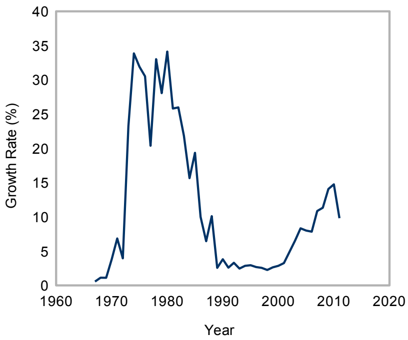
(a) Cumulative



(b) Annual Addition



(c) Growth Rate



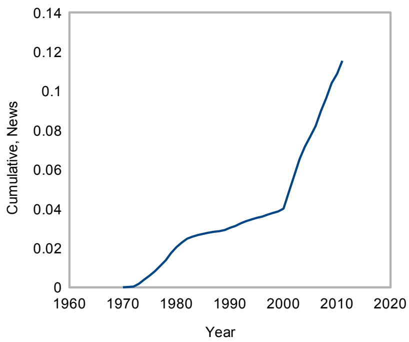
Number of scientific publications. The data on scientific publications over time are plotted in Figure 8. Like the number of manufacturers, a bimodal distribution is present, spanning nearly the same time periods. The magnitude of the second peak in the growth curve (Figure 8c) highlights the sharper difference between the two diffusion periods in this case, also visible in the steep slope at the end of the cumulative curve.

Number of popular press articles. Data on the number of popular press articles related to wind power are presented in Figure 9. A bimodal distribution is present, this time with an earlier first period and longer spacing in between. The same tell-tale signs are the multiple peaks in the annual additions curve (Figure 9b), the tooth in the growth curve around 2002 (Figure 9c), and the sharp change in slope in the cumulative curve at the same time period (Figure 9a).

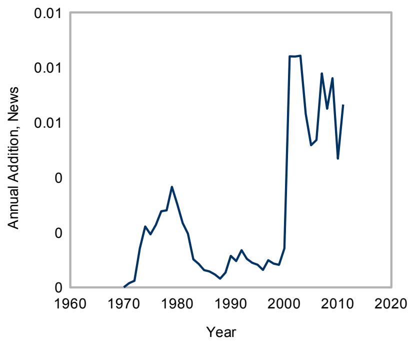
This data set suffers from an important limitation which should be explicitly highlighted. Due to the sources present in the news aggregator that

Figure 9: Number of popular press articles, search term "wind power"

(a) Cumulative



(b) Annual Addition



(c) Growth Rate

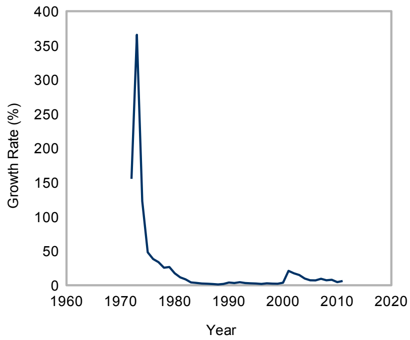
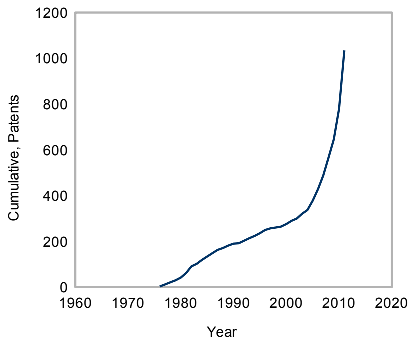
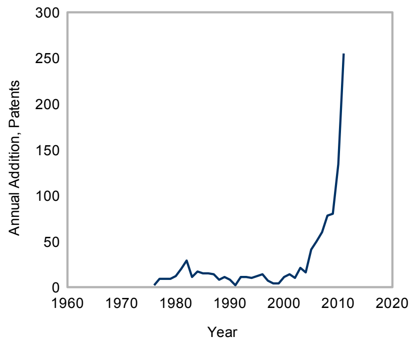


Figure 10: Number of patents, search term in title (wind and (turbine or machine))

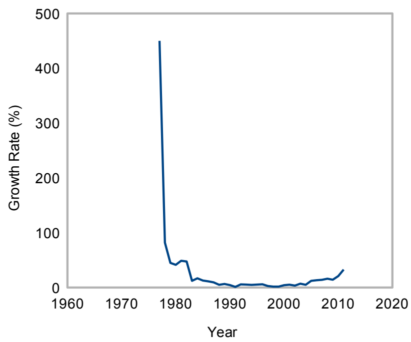
(a) Cumulative



(b) Annual Addition



(c) Growth Rate



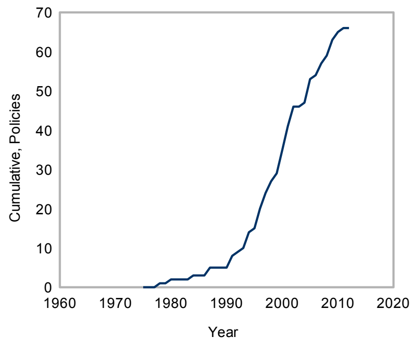
was used for data collection and the native language of this study's author, the data are sharply biased toward English-language news. Moreover, the vast majority of sources available are from the USA. Due to both data availability and time constraints, it was outside the scope of this study to look at how this USA-slanted bias would compare to a more global view of historical presence of information on wind power in the news.

Number of patents. The data on the number of patents related to wind power technology granted each year are plotted in Figure 10. While these curves are closer to the ideal case than most of the data seen so far, they also appear to be quite early in overall development, similar to those for installed capacity. One notable departure is the beginning of an upward slope in the growth curve (Figure 10c) noticeable in the last few years.

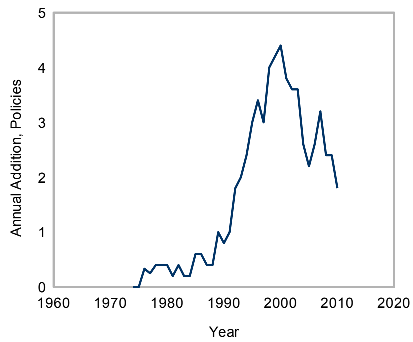
This data set may have some bias given that it comes entirely from the USPTO. In many cases, an inventor or assignee may file with the USPTO

Figure 11: Number of national policies

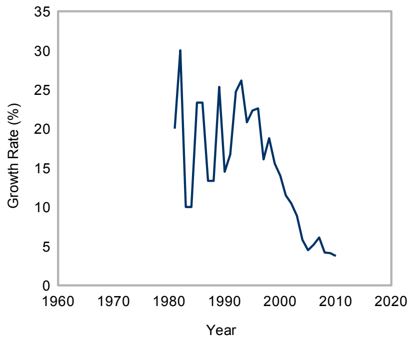
(a) Cumulative



(b) Annual Addition (Moving average filter applied)



(c) Growth Rate (Moving average filter applied)



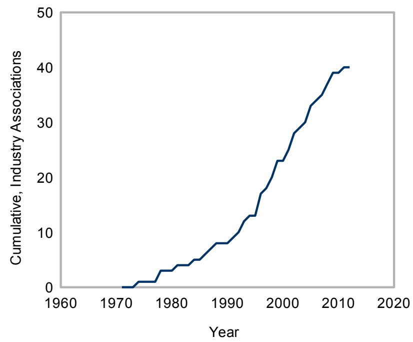
even if they are based in another country, so it is difficult to know just how narrow this data set really is.

Number of national policies. Data regarding national policies related to wind power technology are plotted in Figure 11. These data largely show behavior similar to an ideal diffusion case, with the Gaussian beginning its descent and the S-curve approaching its plateau. The Gaussian peak, representing the year with the largest number of new countries introducing legislation related to wind power, falls around the year 2000. Again, the choppiness in the growth rate curve arises from the discrete nature of the data set.

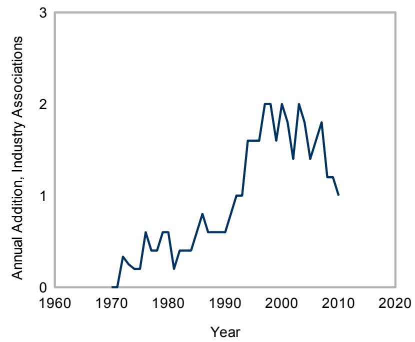
Number of national industry associations. Figure 12 shows the results of the number of national industry associations founded over time.

Figure 12: Number of national industry associations

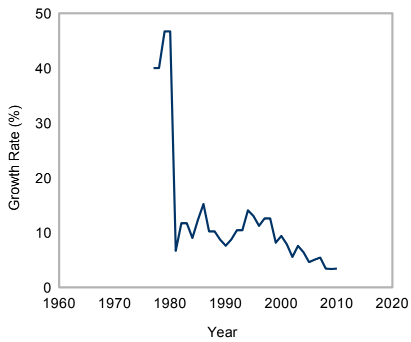
(a) Cumulative



(b) Annual Addition (Moving average filter applied.)



(c) Growth Rate (Moving average filter applied.)

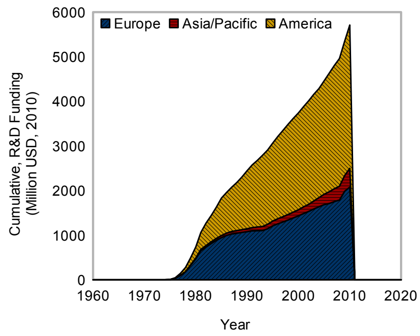


Here, except for the fact that the data set is somewhat chaotic due to the fact that it contains so few data points, the overall trends follow the generalized diffusion path expected in the ideal case. The peak year for the founding of new organizations appears to have fallen somewhere between 1997 and 2003.

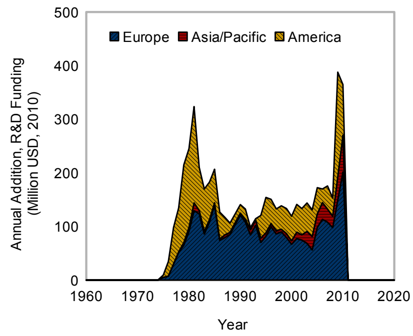
R&D funding. Research and development funding figures are depicted in Figure 13. Here, a clear bimodal distribution is present in the annual additions curve (Figure 13b). The second peak arrives several years later than those found in most of the other datasets. The data is broken into funding by region where it is interesting to see how funding in Europe has been relatively flat since as far back as the late 1970's, while that in the Americas has fluctuated significantly. The recent spike, which could be the beginning of a second Gaussian peak, is largely a result of increased funding

Figure 13: Research and development funding

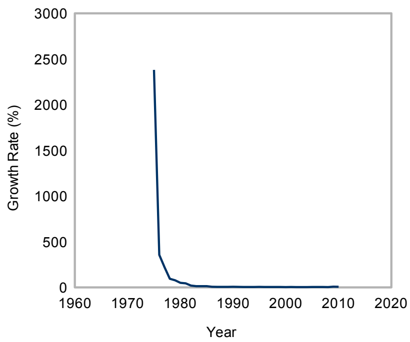
(a) Cumulative



(b) Annual Addition



(c) Growth Rate

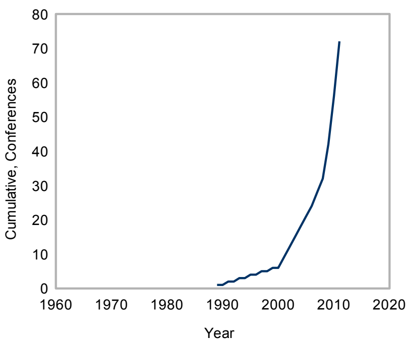


in the Americas.

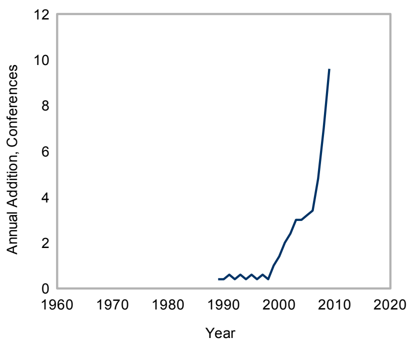
Number of conferences. Data for conferences, workshops, and trade shows can be seen in Figure 14. These curves appear to show an approximation to idealized diffusion, with some departure from a smooth curve. This is most apparent in the sawtooth pattern found on the growth rate curve (Figure 14c). It is worth noting that the lack of a bimodal distribution could be related to the difficulty in finding archived information as far back in this category as in others.

Figure 14: Number of conferences, workshops, and trade shows

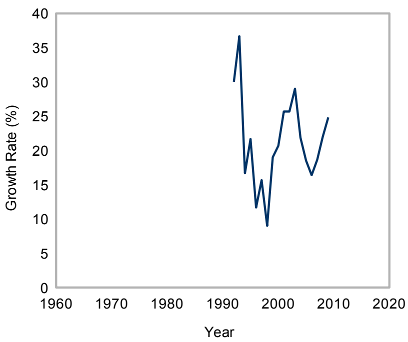
(a) Cumulative



(b) Annual Addition (Moving average filter applied.)



(c) Growth Rate (Moving average filter applied.)



4.4 A data-backed narrative of the history of wind power

In order to gain more insight on the historical development of the wind power technological system, the data on the various system components are normalized to their respective maxima and plotted together in Figure 15. In the spirit of traditional innovation system studies, one can take a closer look at these plots and "tell a narrative" of the development of this particular innovation system. One such narrative follows.

Beginning at the left of Figure 15a, the first peak starting to rise is that of news articles in the popular press, around 1972. Starting around the same time, but with a slower growth rate, is the rise in scientific publications related to wind power. These data sets correspond to user practices, culture, and creation of legitimacy and knowledge development and diffusion, respectively. For each of these cases, the media act as channels of communication, facilitating a spread in awareness and information about a new innovation: Devices designed to harness the energy of passing winds to provide useful electricity.

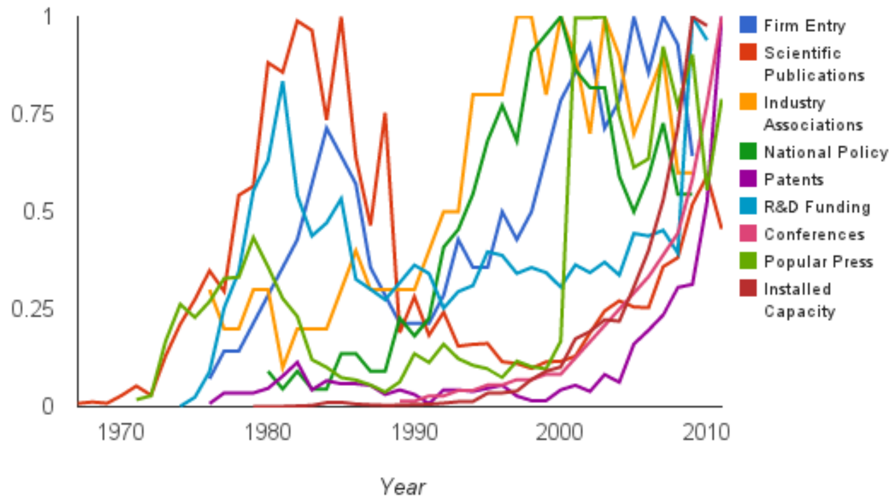
The buzz created by these information sources gives a nudge to the next two system components to take off around 1974, research and development funding and the number of manufacturers. Decision-makers in national governments encounter information on wind power innovations more frequently, and these formerly radical ideas gain credibility over time, so that funding is diverted to explore their feasibility. This suggests a system interaction in which creation of legitimacy leads to mobilization of resources. At the same time, the growing awareness (popular press) and body of knowledge (scientific publications) around wind power push innovators, entrepreneurs, and engineers with tangentially related skills and backgrounds into the new field of wind turbine design and manufacturing. Here, legitimacy and knowledge development have an impact on the system function guidance of search. The race to commercialization begins.

Around this same time, the earliest industry associations are formed, establishing social networks through which resources can be pooled, ideas shared, and partnerships formed. Around 1977, the first (admittedly small) peak in patenting begins as newly formed wind turbine manufacturers, as well as independent inventors, seek out patent protection for their ideas, given the immense perceived potential of the budding industry. Not long after, national policies begin to take shape, now needed to codify the rules governing appropriate use of this new technology and establish norms and regulations for its exchange on markets. Clear causal relationships might remain elusive in this period, but the data would suggest interactions occurring between technology, policy, and guidance of search.

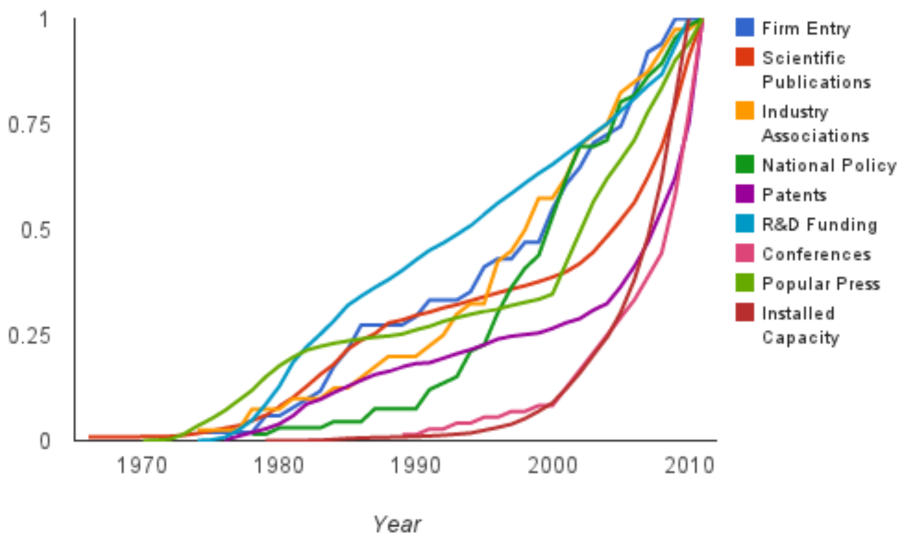
In the early half of the 1980's, the great momentum gathering in the innovation system suddenly turns around. Popular press coverage is the first element to dwindle, followed by R&D funding. After a short time

Figure 15: Collected system component data, normalized and co-plotted

(a) Annual Additions



(b) Cumulative



lag, this downward trend is also seen in scientific publications and founding of new firms. Perhaps the great advances that were hoped for were not coming to fruition as quickly as expected. Bucking the trend are national policies and industry associations, which seem to continue on a gradual upward slope through the following two decades. One interpretation of this could be that, while overall system momentum slowed, the seed had already been planted, and a small group of dedicated individuals in government and industry would continue the important work of laying foundations for the fledgling socio-technical system. As founding of new firms dropped, exploration of the fundamental science dwindled, and research funding was cut, the true believers worked on network-building (industry associations) and policy-making to facilitate the eventual incorporation of the technology as a component to a new dominant system.

In the early 1990s, the wind power innovation system hits rock bottom, but a new push is just around the corner. Around 1995, research and development funding (resource mobilization) bounces back a bit and new companies begin to be founded (entrepreneurial activity), with the hope of bringing better products to market. Over the next five years, policy initiatives and industry associations continue to form, peaking around the turn of the century. At this same time, the presence of wind power in the popular news media sees a sudden surge. Within the next few years, new wind turbine manufacturers spring up all over the world. Going hand-in-hand with this growing field of competitors, patent grants related to wind power begin to sky-rocket, including not just mechanical component designs, but new generator architectures and algorithms for power management in large scale wind farms. All the while, through the first decade of the new millenium, the actual deployment of wind power in terms of total installed capacity takes off beyond the expectations of even the strongest supporters of wind power ...

This type of narrative for the development of a socio-technical system around a new technology is similar in many ways to the qualitative analysis found in more traditional innovation studies. One significant difference is that this story looks at a global innovation system, capturing a bird's-eye view of overall trends, while missing a good deal of regional and national detail typically found in TIS studies. The use of quantitative data to this point has only provided a messy, yet reality-grounded figure as a backdrop and a basis for the story. In its guidance of the narrative, it also focused causal descriptions on endogenous effects. Even with all these caveats, this exercise in storytelling is useful to link the method employed here back to past work within the field of innovation studies.

4.5 Modeling the data as diffusion curves

Once data sets corresponding to the system components listed above were collected, the first step taken from diffusion studies was to fit each non-cumulative data set with a generalized Gaussian function, of the form:

$$f(x) = a \exp \frac{-(x-b)^2}{2c^2} \tag{1}$$

where a is the peak height, b is the peak center position, and c defines the peak width as follows:

$$c = \frac{\text{Full Width at Half Maximum}}{2\sqrt{2\ln 2}} \tag{2}$$

This was performed with a Matlab function [O'Haver, 2012] in which values of a, b, and c were tested for goodness-of-fit with the data set, and optimized according to a Nelder-Mead Simplex search method. The function also had the capability to fit a linear combination of Gaussian functions of the form:

$$f(x) = \sum_n a_n \exp \frac{-(x-b_n)^2}{2c_n^2} \tag{3}$$

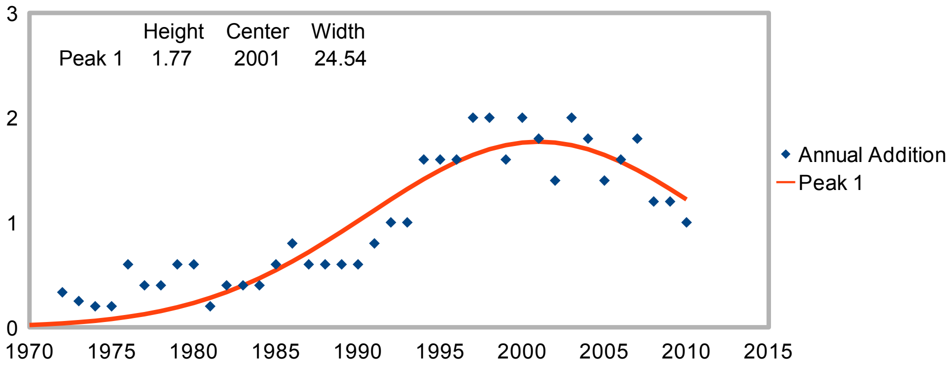
This was used on a case-by-case basis when two peaks were apparent based on simple visual inspection of the plotted data. Figure 16 shows two examples of the curve fitting results. Figure 16a shows an example of a single peak fit and Figure 16b shows one with a double peak.

After fitting the data, the parameters a, b, and c could be used to segment the curves into adopter groups. Table 2 summarizes the inputs and outputs of this process.

It is clear from the table that the fitting procedure did not give reasonable results for all datasets. Namely, for Number of patents, Number of conferences, and the second peaks for R&D funding and Number of scientific publications, the peak center timing and height are unreasonably large. In all of these cases, the data show a peak which is very early in its trajectory. Amidst this lack of information with which to work, the algorithm seems to tend toward large Gaussians which leave the realm of what might be deemed reasonable values for this type of study. The only route to forcing the algorithm to more reasonable values would be the provision of more information, such as more time series data as the system development continues to unfold, or some estimation about when the peak might be reached. The latter method, however, would be quite heavy-handed, and simply force the peak to a shape based on a highly subjective assessment. For the purposes of this study, the curves were left as they are.

Figure 16: Two examples of curve-fitting results

(a) Single peak — Industry associations



(b) Double peak — Firm entry

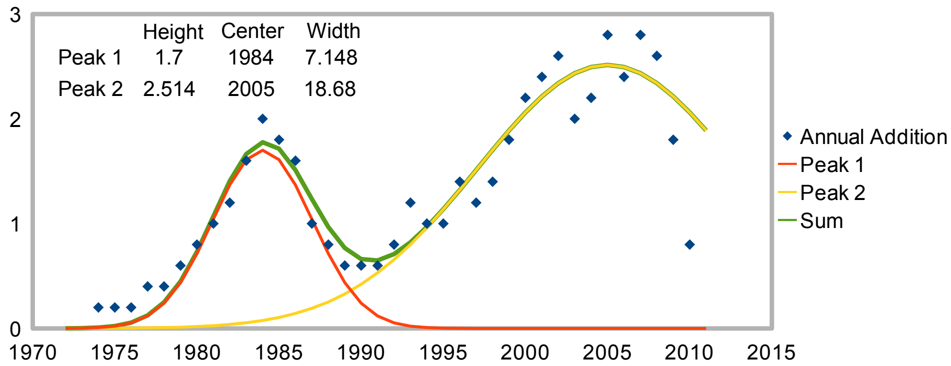


Table 2: Input/Output of Gaussian parameters from curve fitting procedure

Data set	Input	Output, peak #1			Output, peak #2			
	Peaks	Center	Height	Width	Center	Height	Width	Error
Number of manufacturers	2	1984	1.7	7.148	2005	2.514	18.88	7.7%
Number of scientific publications	2	1983	1.599	10.57	2570	7.69E6	164.7	8.05%
Number of national industry associations	1	2001	1.77	24.54				12.32%
Number of national policies	1	2001	3.871	16.1				8.63%
Number of patents	1	5715	Inf	232.4				5.24%
R&D funding	2	1981	209.1	6.713	3131	4.3E16	326.6	11.72%
Number of conferences/trade shows	1	8672	Inf	421.8				2.44%
Number of popular press articles	2	1978	1.03E-3	12.81	2009	3.39E-3	13.17	8.16%
Installed capacity	1	2045	1.55E6	30.72				3.44%

4.6 Timing of adoption

To continue the analogy of studying these system components as diffusion phenomena, the best-fit curves determined previously were segmented in an adopter-grouping scheme similar to that in Rogers [1962]. This scheme is based on breaking the Gaussian up according to number of standard deviations from the mean, and can be seen in Figure 1 by the vertical lines breaking the Gaussian distribution into segments, which are also given names in the figure. Alongside the discrete grouping system, a continuous metric was used, henceforth called the Innovativeness Score (IS). This simply shows the exact number of standard deviations from the mean a given timing represents:

$$IS_{i,j} = -(t_{i,j} - t_{mean,j})/\sigma_j \tag{4}$$

for the i^{th} adopter in the j^{th} system component.

This categorization allows for an event on a given system component diffusion curve, in a given year, to be scored with a degree of innovativeness relative to other events, both on the same diffusion curve and others. It is effectively a transformation of the time dimension from a fixed scale based on absolute years (i.e. the country implemented its first policy in 1980) to a relative scale based on the totality of adoption events over time (i.e. the country's first policy was implemented 0.6 standard deviations before the overall average implementation year) . This makes it easier to compare events on two different diffusion curves, since in real years, different system components diffuse at different rates and are centered at different years.

Following this definition, an IS of 0 signifies an adopter who adopts at exactly the average year (the peak position on an idealized period adoption curve), while a positive IS signifies adoption before the average (high innovativeness), and a negative IS signifies adoption after the average (low innovativeness).

Table 3 shows the timing of the various adopter categories for each of the system component diffusion curves. Note that due to overlap, there are cases in which a number of years could fall into multiple groupings for the system components which were modeled as a series of two Gaussians. Also, in several cases, no events could possibly be found in a particular grouping because the earliest year for that grouping has not yet been reached. For example, one can not possibly find Laggards in the number of national industry associations because it is not yet 2018, the first year in which an adoption event for this system component would be tagged as a Laggard. Such impossible categories are italicized in Table 3.

4.7 Comparing innovativeness across system components

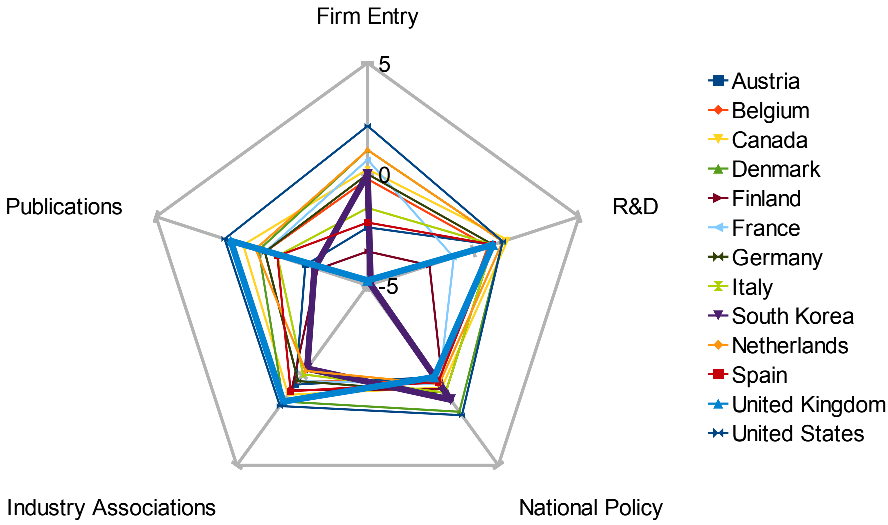
In order to make comparisons of innovativeness from one data set to the next, one must begin with an appropriate grouping of data across the categories. One such grouping that is rather straightforward is associating the data with sovereign nations. For a subset of the data sets, this is both clear in meaning and possible given the methods used in data collection. For example, Number of manufacturers can be grouped to nations by analogizing adoption as the earliest year in which a firm based in a given nation begins operation. Similarly, Number of scientific publications (with adoption being the earliest year in which a publication's author is affiliated with an organization in a given nation), Number of national industry associations (with adoption being the founding year of a nation's industry association), Number of national policies (with adoption being the earliest establishment of a policy in a given nation), and R&D funding (with adoption being the first year in which a given nation earmarked R&D funds for wind power) can all be broken down to the level of national adoption. For the remaining categories, either some aspect of the data collection process precludes the possibility of this disaggregation, or the Gaussian fitting procedure already yielded numbers which cannot reasonably be used for further analysis (i.e. Number of patents). By bringing this information together, one can explore the degree of innovativeness found in various nations across different system components, as well as exploring relationships between innovativeness of a given nation, success in the deployment of wind power, and additional factors.

A comparison of IS across all five of these system components for 13

Table 3: Adopter groupings for all system components. Italicized entries denote categories which have not yet started

Data set	Peak	Innovator (before)	Early Adopter	Early Majority	Late Majority	Laggard
Number of manufacturers	1	1975	1980	1984	1989	1993
Number of manufacturers	2	1981	1993	2005	2018	*2030*
Number of scientific publications	1	1970	1977	1983	1990	1997
Number of scientific publications	2	*2358*	*2464*	*2570*	*2677*	*2783*
Number of national industry associations	1	1970	1986	2001	2017	*2033*
Number of national poicies	1	1981	1991	2001	2012	*2022*
Number of patents	1	*5416*	*5566*	*5715*	*5865*	*6015*
R&D funding	1	1973	1977	1981	1986	1990
R&D funding	2	*2710*	*2921*	*3131*	*3342*	*3552*
Number of conferences	1	*8129*	*8401*	*8672*	*8944*	*9216*
Number of popular press articles	1	1962	1970	1978	1987	1995
Number of popular press articles	2	1993	2001	2009	*2018*	*2026*
Installed capacity	1	2006	*2026*	*2045*	*2065*	*2086*

Figure 17: Spider plot of Innovativeness Scores in 5 system components for 13 countries— A positive Innovativeness Score indicates earlier than average movement/adoption, while a negative score indicates later than average



countries is plotted in Figure 17. It is apparent from this spider plot that, while some degree of correlation can be seen in the roughly regular pentagonal shape of the lines for most countries (the unbolded lines in the figure), there are also numerous examples of drastic differences in innovativeness across system components. For example, the line for the United Kingdom (light blue, in bold) shows agreement across four of the components, hovering around an Innovativeness Score of 2 (signifying early mover status), while for Firm Entry, it spikes to a score of -5 (signifying an extreme laggard). A different mismatch can be seen for South Korea (purple, in bold) and R&D funding.

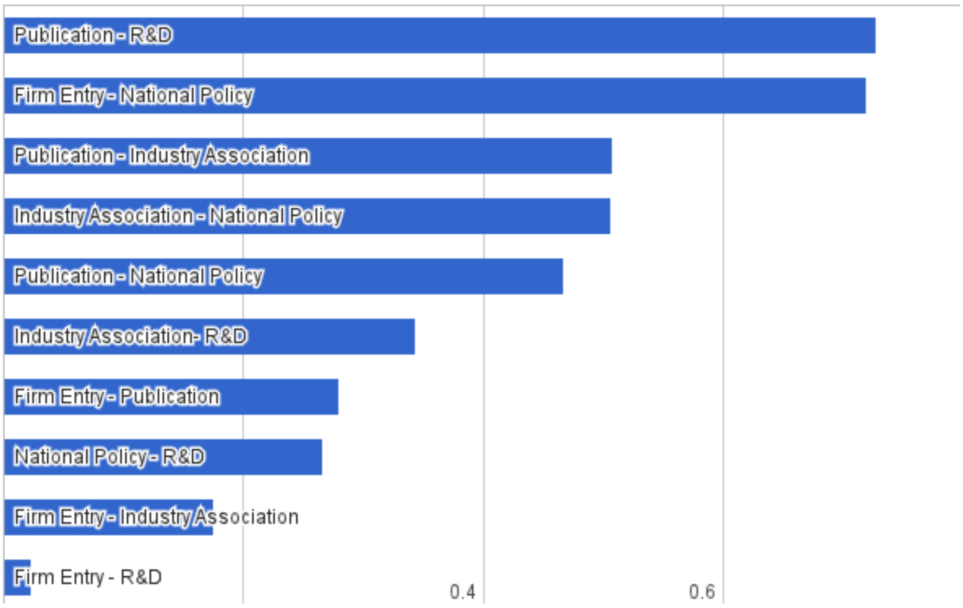
To explore this relationship more quantitatively, the Pearson's sample correlation coefficient was calculated for the full dataset across any two system components, giving a total of 10 pairs to explore.

$$r_{xy} = \sum_{i=1}^{n} \frac{(x_i - \mu_x)(y_i - \mu_y)}{(n-1)\sigma_x \sigma_y} \tag{5}$$

where μ is the mean value, σ is the standard deviation, and n is the number of data points in a given sample.

The results are plotted in Figure 18. This figure presents the first quantitative glimpse into the relationships between system components in the

Figure 18: Correlation between Innovativeness Scores for 10 pairs of system elements

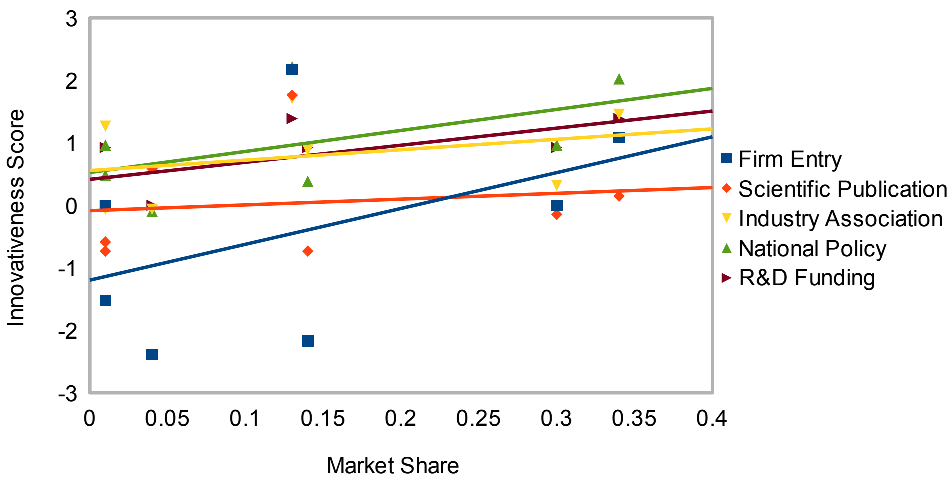


wind power innovation system modeled here. Some of the relationships seem perfectly logical. For example, the highest correlation found was for innovativeness in R&D funding and Scientific publication (roughly corresponding to the system components resource mobilization, scientific knowledge, and guidance of search and knowledge development and diffusion, respectively). Conventional wisdom would suggest that as R&D funding is distributed to academics and university-level research centers, scientific studies are carried out and results are published in academic journals. Therefore, those nations who fund R&D earliest should also reap the outputs early in terms of scientific publications.

At the opposite end, Firm Entry and R&D funding show a correlation that, while positive, is very weak. This would seem to refute the argument that government support of basic research is a prerequisite for encouraging early movement in developing a thriving industry. On the contrary, Firm Entry's highest correlate is National Policy, suggesting that the more fruitful role to be played by governments is the establishment of codified rules to facilitate the adoption of the new technology into incumbent-dominated markets.

At this point it should be noted that one must remember that these relationships have been gleaned from a data set for just one technology, that of modern wind power for electricity generation. It is much too early to make further leaps in conjecture by suggesting that these relationships

Figure 19: Market share versus Innovativeness Scores for 7 countries



would apply to a different technology, even one that might be very similar in many respects (i.e. another renewable energy technology). The importance of these findings to a general audience interested in technology development lies more in the fact that they show a way for testing hypotheses about such general phenomena. For example, the somewhat non-intuitive low degree of correlation between resource mobilization/guidance of search (R&D funding) and entrepreneurial activity/industry development (Firm entry) could be tested for several other technologies from a variety of categorizations (energy, consumer durables, medical practices, etc.). Depending on how well these general system element concepts correlate across a large number of technologies, the generality of this relationship could be determined.

4.8 Innovativeness and system success

Another potentially interesting area of exploration this study opens up is the relationship between innovativeness and relative success of technological deployment. Conventional wisdom would hold that often, early movers establish relative advantage over those who are less innovative. Having had a longer period of time in which system building has occurred, these early movers should have larger networks of support from those with interests aligned with the technology's development, more intricate support structures in the forms of public policies and lobbying groups, a more advanced understanding of the possibilities and limitations of the technology, and a greater progress along the technology's learning curve [Dannemand Anderson, 2004].

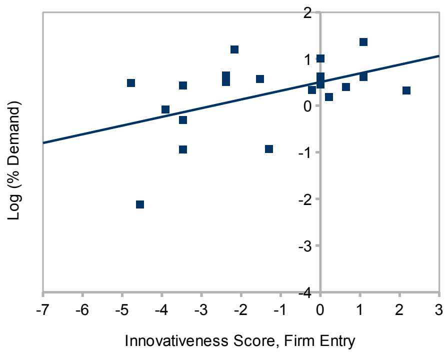
With the quantitative metrics determined above for degree of innovativeness, it is only left to determine what metric fairly represents success of the technology's innovation system. This cannot be done without a dose of subjectivity. This study uses two metrics for success. The first is the percentage of total market share held by a nation's domestic companies for all deployed wind power around the globe up to 2006. This metric shows which nations have had success with industry-building, which for some might be considered a valid goal of the innovation system. The second metric used is the percentage of a nation's total electricity demand met by wind power based on numbers from around 2009-2010, plotted on a logarithmic scale. This gives some type of size-weighted metric for domestic deployment of the technology in question, and the logarithmic scaling serves to focus attention on order-of-magnitude differences rather than absolute values.

Figure 19 shows the market share (as defined above) held by wind turbine manufacturers in seven countries plotted against the values of those countries' IS in five system components. There is clearly some trend visible, showing that more innovative nations (positive values on the y-axis) have built industries that successfully compete globally, with higher market shares than the latecomers (negative values on the y-axis). This upward slope is apparent in all of the plotted system elements, but it is quite varied in scale. It appears to be most pronounced for Firm Entry and National Policy, while it is nearly negligible for Industry Association and Scientific Publication. R&D Funding shows a trend which is clear, but somewhat weak.

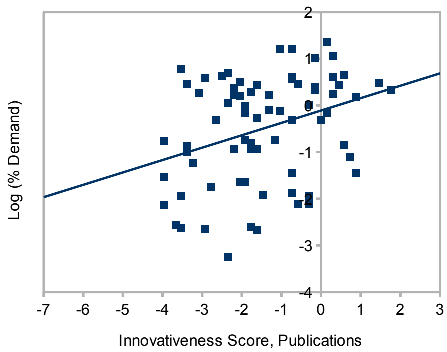
Figure 20 shows the percent of electricity demand met by wind power on a logarithmic scale as a function of innovativeness in each of the five system components separately. The first point of note is that an upward slope is present to a varying degree in all of the five plots. This suggests that more innovative nations (positive values on the x-axis) have generally more effectively introduced wind power within their borders. This trend is strongest for National Policy, followed closely by Industry Association. Interestingly, the trend for Firm Entry is one of the weakest present. Given the apparent importance of innovativeness in Firm Entry in the building of a competitive industry (seen in Figure 19), its lower priority here suggests that one can build a globally competitive industry without necessarily having a large domestic market. This is a somewhat non-intuitive result, but could simply mean that the niche-type markets needed for early technology development can be quite small while still providing an effective springboard to global markets once a manufacturer is established.

Figure 20: Electricity demand met by wind versus Innovativeness Score

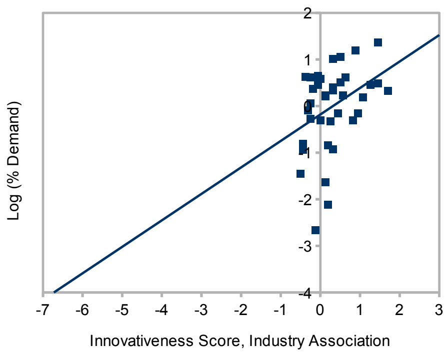
(a) Firm Entry (20 points)



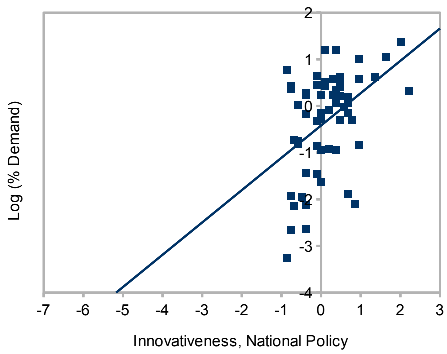
(b) Scientific Publication (73 points)



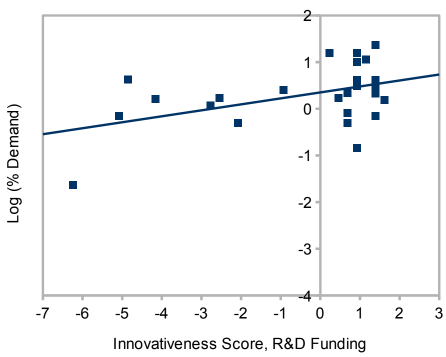
(c) Industry Associations (38 points)



(d) National Policy (60 points)



(e) R&D Funding (27 points)

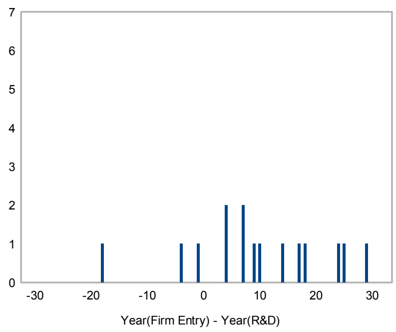


4.9 Event timing in real years

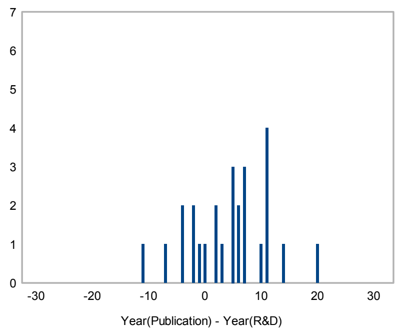
Momentarily stepping away from the diffusion-style analysis that has preceded, another interesting area of analysis facilitated by this data collection is the search for trends in ordering of events in the innovation system. Sticking to country-level analysis, it is possible to examine the distribution of difference in timing between, for example, the founding of the first domestic manufacturer and the establishment of the first national policy over a large sample of countries. In these cases, the time dimension is one of absolute scale (in other words, real years), as opposed to the relative scale developed and applied previously through the use of the Innovativeness Score.

Figure 21: Event ordering — R&D funding first

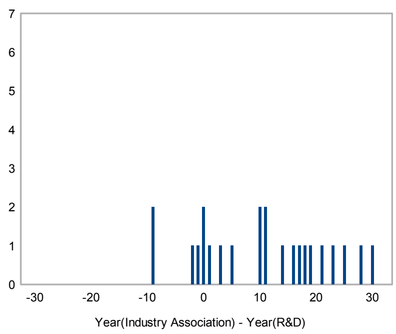
(a) Firm Entry and R&D Funding, 15 countries



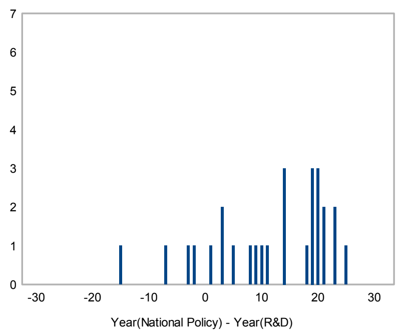
(b) Publication and R&D Funding, 26 countries



(c) Industry Association and R&D Funding, 23 countries



(d) National Policy and R&D Funding, 27 countries

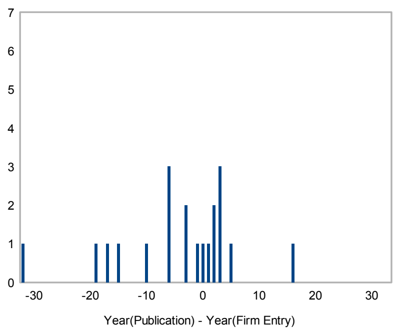


This has been carried out for the five system components which were included in the earlier analysis on Innovativeness Scores, choosing any two and comparing them over as large a sample as was available from the collected data. The resulting histograms are plotted in Figures 21 – 23.

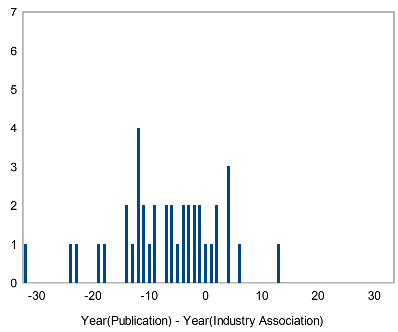
The charts in Figure 21 compare the timing of earliest R&D funding to the other four data sets. In Figure 21a, it is apparent that, while a few data points defy the trend, in the majority of cases a country's earliest investment in R&D funding precedes the founding of its first wind turbine manufacturing firm. Similarly, Figure 21b shows that the earliest scientific publication from a given country tends to come after its first R&D investment, although these two events seem to occur closer together in time. Continuing through Figures 21c and 21d, the same general relationship holds. This suggest that, when looking at these five data sets in a single country, the tendency is for R&D funding to be the earliest adoption event to occur in real time.

Figure 22: Event ordering— Publication is relatively early

(a) Publication and Firm Entry, 20 countries



(b) Publication and Industry Association, 39 countries



(c) Publication and National Policy, 60 countries

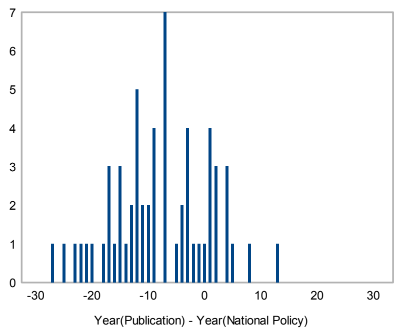


Figure 22 shows the timing difference between the first scientific publication from a country and the remaining three data sets. In Figure 22a, it can be seen that firm entry and publication tend to occur around the same time, within roughly five years of one another. A handful of data points fall outside of this range, with the majority showing publication occurring first. Figure

22b suggests that the first scientific publication in a given nation tends to precede the establishment of an industry association. This is a relationship that might be expected based on a linear model of technology development, as academic output would create opportunities for applications in society, around which an industry might grow. A similar relationship can be seen in Figure 22c, this time between scientific publication and the first national policy in a given nation.

Figure 23 shows the timing differences for the remaining data set pairings. Recall from Figures 21–22 that industry association formation and first national policy have tended to occur later, while firm entry has occurred somewhat closer in time to scientific publication. Figure 23a suggests that the first manufacturing firm to enter the market in a given nation tends to do so within +/- 10 years of the establishment of an industry association in that nation. While it may seem strange to have an industry association founded before any manufacturing firms, it should be remembered that manufacturing only represents one step in the value chain, and industry associations can just as reasonably grow up around financiers, independent power producers, and component manufacturers. In Figure 23b, the tendency for the first firm entry to occur before a first national policy is put in place is evident. This supports the idea that policy-makers tend to be reactive, either due to pressure from a growing industry for supportive legislation or due to their own increasing awareness of the needs of regulation for a new industry. It seems less common for the foresight of policy-makers to pave the way for an industry to start up. Finally, Figure 23c shows a roughly equal distribution between industry association founding and national policy creation occurring first, suggesting plausibility for two directions of causality.

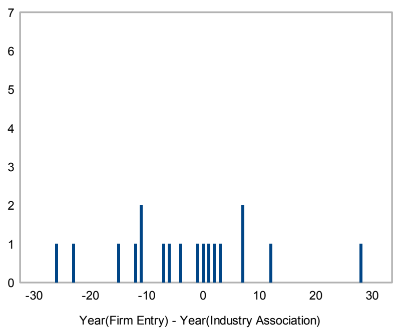
To summarize these generalizations, Figure 24 shows a flowchart which maps the relationships enumerated above. For early system development at the national level, the data support these orderings, with single arrows representing forward progress through time and double arrows representing co-development. The thicknesses of the arrows roughly correspond to the measure of correlation between data sets presented in Figure 18. It is important to note that an underlying assumption to this analysis is that each national innovation system develops in isolation from all others.

5 Conclusions and Future Work

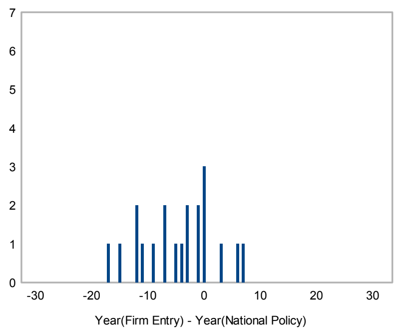
This study set out to describe and attempt to apply a novel method for quantitatively exploring the nature of technological innovation systems. At the heart of the method lies the idea of wedding quantitative, data-centered approaches from technology diffusion studies with the broad system-level thinking found in innovation and technical change studies. In doing so, abstract system concepts from the latter were mapped to quantifiable data

Figure 23: Event ordering— Co-formation of system elements

(a) Firm Entry and Industry Association, 18 countries



(b) Firm Entry and National Policy, 20 countries



(c) Industry Association and National Policy, 38 countries

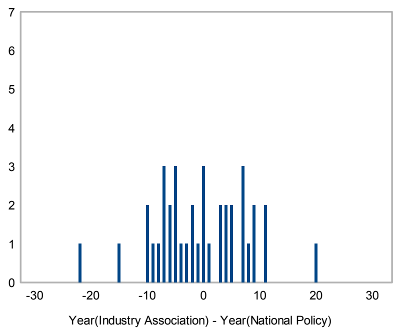
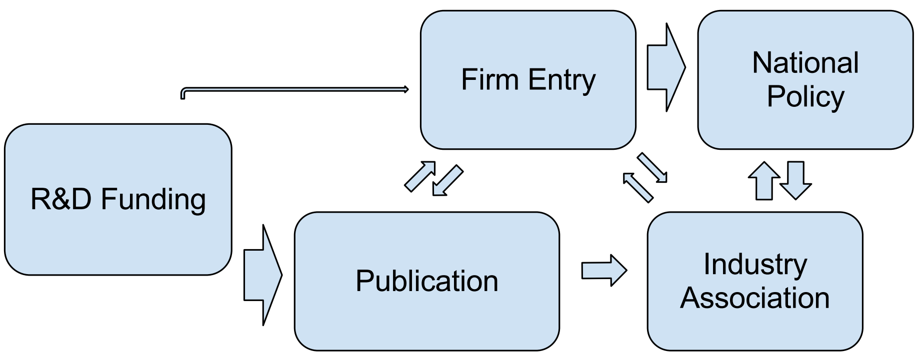


Figure 24: Ordering of innovation events for early system development



sets which in some way captured their meaning. The data was collected and manipulated according to the conventions in diffusion studies in order to both chart the historical development of the technological system in question and establish metrics of innovativeness at the country-level. These innovativeness scores were then compared across different categories in order to show how this method can help elucidate the nature of relationships between system components. Additionally, the numeric innovativeness scores were compared against various metrics of system success in order to test the hypothesis that early movers should have greater success in deploying a technology. Finally, the time-ordering of innovation events was studied over the sample set available in order to lay out plausible causal chains in early system development supported by the data.

As this represents only a first attempt at applying this method, there are many outstanding questions about its usefulness, rigour, and best practices. One key limitation on which the entire study rests is the mapping of complex concepts from system studies to quantifiable data. By their very nature, these complex system components are difficult to capture in simple, straightforward ways. One could reasonably propose a whole series of mappings which differ from or augment those used in this study. The quantified innovativeness metrics miss the intended mark if the data from which they are derived do not fairly represent the innovation system components as they are intended.

To take an example of a potential improvement in this area, recall the criteria used for the national policy data set. For each country, the earliest policy put in place at the national level dealing explicitly with wind power, and going beyond simply R&D funding was included in the data set. However, not all policies are equal in practice. This aggregation process treated with equal weight such diverse policies as feed-in tariffs, national energy roadmaps, and wind turbine siting standards. Perhaps a more accurate picture would come from mapping the policy developments in categories, such as market-based interventions, tax incentives, energy roadmaps, and technical standards. These various types of policies might then correspond to different system functions such as market formation for market-based interventions or legitimization for energy roadmaps. Similar ideas can be imagined for many of the other data sets, fleshing out the proposed mapping into data conglomerates of a complexity more closely mimicking that of the complex system element concepts. This could give a much more nuanced picture of the system under study.

Another important limitation to this method lies in the end-point of diffusion-style research. With adoption of various system components at the heart of the study, the focus tends to be on early development. In the case of technology diffusion, the researcher's interest wanes after a user has adopted (i.e. bought the technology). In the case of an innovation system, a detailed understanding will only come from looking beyond simply the timing of adoption and following developments in *how* the adopted system component is used and develops over time. In many cases, the methods from diffusion studies could still be applicable by simply changing the defined adoption event to a series of meaningful system development events. Returning to the example of national policies, this could mean tracking particular changes in regulations over time rather than simply the year of first introduction.

As mentioned earlier, one key to realizing the full potential of this method would be to apply it to several different technologies. Only then could the big questions about the nature of innovation systems and the relationships between their components begin to be answered. As a starting point, a future study might keep a very similar framework to this one, but look at another renewable energy technology and tease out the similarities that arise in the quantified system element relationships, success predictors, and plausible causal chains identified in this study.

A Data and Sources

Table 4: Adoption events and country level performance (FE=Firm Entry, SP=Scientific Publication, IA=Industry Association, NP=National Policy, RD=R&D Funding, MS=Market Share, IC=Installed Capacity, and EC=Electricity Consumed)

Country	Year					MS (%, 2006)[1]	IC (MW, 2010)[2]	EC (TWh, 2009)[3]
	FE[4]	SP[5]	IA[6]	NP[7]	RD[8]			
Afghanistan				2009			0.075[9]	1.42[10]
Albania			2011				0	4.31
Algeria		2004		2004			0[11]	32.9
Argentina	1990	1995	1996	1999			60	111.21
Australia		1981		1998	1979		1880	240.4
Austria	1995	1997	1993	2000	1977		1011	68.52

[1] from Merrill Lynch, available at http://www.ml.com/media/81290.pdf

[2] Except where otherwise noted, data from GWEC, available at http://www.gwec.net/index.php?id=126

[3] Except where otherwise noted, data from IEA, available at http://iea.org/country/maps.asp

[4] see Table 5 for sources

[5] results compiled from Scopus, available at http://www.scopus.com/home.url

[6] see Table 6 for sources

[7] see Table 7 for sources

[8] results compiled from IEA, available at http://www.iea.org/stats/rd.asp

[9] Source: http://www.seanz.org.nz/seanz-media-releases/155-afghanistans-first-wind-farm-wins-major-nz-industry-award

[10] Source: http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en

[11] Source: http://www.ae-africa.com/read_article.php?NID=2405

Table 4: (continued)

Country	FE	SP	IA	NP	RD	MS	IC	EC
Azerbaijan		2007					0[12]	20.12
Bahrain		1993					0.55[13]	10.19
Bangladesh		1988					2[14]	33.27
Belarus				1994			2[15]	33.17
Belgium	1985	1984	1996	1997	1978		911	91.27
Bolivia				2000			0[16]	5.44
Bosnia and Herzegovina		2004					0[17]	9.31
Brazil		1988	1997	2002			931	428.5
Brunei		2010					0[18]	3.26
Bulgaria		1998	2004	2009			376	35.02
Burma		2011					–	4.83
Cameroon		1995					–	5.01
Canada	1983	1977	1984	1994	1974		4009	568.32
Chile		1996		2005			172	55.78
China	1984	1987	1981	1996		1	42288	3293.21
Colombia		2006					20	43.83
Croatia		1999	2005	1997			89	17.2
Cuba		2010					12	14.87
Cyprus		2007		2010			133[19]	4.93
Czech Republic		1996	1994	2001	2003		215	67.39
Denmark	1979	1982	1978	1980	1975	34	3752	35.49
Djibouti		2011					–	0.23[20]
Ecuador		2010					2	15.34
Egypt		1985		2007			550	116.21
El Salvador		2011					–	5.85
Estonia		2003	2001	1998			149	8.51
Fiji		2007					–	1.02[21]
Finland	2000	2001	1988	1993	1990		197	86.87
France	1981	1984	1996	1996	1985		5660	493.95

[12] Source: http://ebrdrenewables.com/sites/renew/Shared\%20Documents/Country\%20Notes/old\%20website\%20country\%20profiles/Azerbaijan.pdf

[13] Source: http://www.reeep.org/xml/policy-db/BH.xml

[14] Source: http://www.lged-rein.org/database.php?pageid=67

[15] Source: http://ebrdrenewables.com/sites/renew/countries/Belarus/profile.aspx

[16] Source: http://www.energici.com/energy-profiles/by-country/central-a-south-america-a-l/bolivia

[17] Source: http://www.kfw-entwicklungsbank.de/ebank/EN_Home/Sectors/Energy/Project_Examples/Bosnia_-_Wind_Energy.jsp

[18] Source: http://news.brunei.fm/2010/06/22/harness-the-power-of-wind-to-meet-future-energy-demand/

[19] Source: http://www.cyprus-mail.com/wind-farms/sun-aplenty-so-why-wind-chosen-one/20120325

[20] Source: http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en

[21] Source: http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en

Table 4: (continued)

Country	FE	SP	IA	NP	RD	MS	IC	EC
Georgia		2010					–	7.23
Germany	1984	1984	1996	1991	1977	30	27214	587.01
Ghana				1998			0[22]	6.25
Greece		1988	1991	1987	1977		1208	64.31
Guyana		1999					13.5[23]	0.6[24]
Hungary		1997	1999	1996	1999		295	40.04
India	1995	1979	2002	2002		4	13065	645.25
Indonesia		2003		2005			1.4[25]	134.4
Iran	2000	1994		2001			92	174.33
Iraq		1988					–	35.75
Ireland		1981	1993	1984	1976		1428	27.89
Israel		1977	2009	2002			8	49.46[26]
Italy	1991	1988	2002	1991	1977	1	5797	338.72
Jamaica		1990					24	6.86
Japan		1983	2001	1996	1978		2304	1030.7
Jordan		1988		2005			2	12.13
Kenya		1996		2008			5	6.02
North Korea		2007					0.2[27]	18.18[28]
South Korea	1984	2000	2007	1987	2002		380	19.54
Kuwait		1984					–	45.69
Latvia		1996		1995			31	7
Lebanon		1996					1	9.51
Lesotho		2012					–	0.23[29]
Libya		1991		2007			20[30]	24.61
Lithuania		2006	2002	2002			154	11.95
Luxembourg				1994	1993		42	7.77
Malaysia		1992					–	94.28
Malta		2002					–	1.85[31]
Mexico		1994	2005	2001			519	214.8
Mongolia		1995	2008	2007			2.72	3.89
Montenegro		2011					–	0.02[32]
Morocco		1994		2009			286	23.25
Namibia		2007					0.2[33]	3.83

[22]Source: `http://energy.invisibleschoolhouse.net/mod/wiki/view.php?id=159&page=Ghana`

[23]Source: `http://www.wwindea.org/interactivemap/first/`

[24]Source: `http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en`

[25]Source: `http://www.wwindea.org/interactivemap/first/`

[26]Source: `http://www.iea.org/stats/indicators.asp?COUNTRY_CODE=IL`

[27]Source: `http://www.wwindea.org/interactivemap/first/`

[28]Source: `http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en`

[29]Source: `http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en`

[30]Source: `http://madeingermany.de/en/africa/2010/report/show/id/337/title/Construction+of+a+Pilot+Wind+Farm+in+Libya/`

[31]Source: `http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en`

[32]Source: `http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en`

[33]Source: `http://www.wwindea.org/interactivemap/first/`

Table 4: (continued)

Country	FE	SP	IA	NP	RD	MS	IC	EC
Nepal		2009					–	2.57
Netherlands	1979	1981	2005	1996	1975		2237	118.84
New Zealand	2000	1980		2000	1975		506	40.52
Nigeria		1985		2006			1	19.12
Norway	2002	1992	2006	1999	1978		441	118.57
Oman		1998					–	13.63
Pakistan		2002					6[34]	72.44
Peru		2010		2008			1	29.77
Philippines		2006		2002			33[35]	53.14
Poland		1998	1999	2005			1107	142.27
Portugal		1990		2000	1980		3702	51.22
Qatar		2002					–	20.09
Romania		1995					462	53.52
Russia		1994	2003	2009			9	913.51
Saudi Arabia		1985					–	186.73
Senegal		1998					–	1.93
Serbia		2007					–	31.49
Singapore		1991		2001			0[36]	39.6[37]
Slovakia		1997	1999	2001	2008		3	28.48
Slovenia		2004		2000			0	13.99
Somalia		1992					–	0.26[38]
South Africa	2005	1987	1998	2005			8	232.23
Spain	1994	1988	1987	1997	1977	14	20676	287.71
Sri Lanka		1978					3[39]	8.23
Sudan		1991					–	3.99
Sweden		1982	1986	1994	1975		441	137.09
Switzerland		1979	1998	1991	1977		42	63.53
Syria		2008					0.4[40]	31.31
Tanzania		1999		2010			0.009[41]	3.56
Thailand		1985		1992			5[42]	140.08
Trinidad and Tobago		2004					–	7.72
Tunisia		2004		2005			114	13.41
Turkey		1992	1992	2001	1992		1329	170.6
Uganda				2011			0	0.9[43]
Ukraine		1998	2008	1997			87	163.49

[34] Source: http://www.wwindea.org/interactivemap/first/
[35] Source: http://www.wwindea.org/interactivemap/first/
[36] Source: http://www.ema.gov.sg/page/35/id:68/
[37] Source: http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en
[38] Source: http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en
[39] Source: http://www.worldenergy.org/documents/wind_country_notes.pdf
[40] Source: http://www.wwindea.org/interactivemap/first/
[41] Source: http://www.worldenergy.org/documents/wind_country_notes.pdf
[42] Source: http://www.windpowermonthly.com/news/1118747/Thailand-buys-200MW-Siemens-wind-turbines/
[43] Source: http://www.indexmundi.com/g/g.aspx?v=81&c=af&l=en

Table 4: (continued)

Country	FE	SP	IA	NP	RD	MS	IC	EC
United Arab Emirates		1995					0.85[44]	75.76
United Kingdom	2006	1973	1978	2000	1977		5204	372.19
United States	1974	1971	1974	1978	1975	13	40180	4155.92
Uzbekistan		1995					0[45]	44.97
Venezuela		2005	2009				0[46]	85.89
Vietnam		2005					18	68.91
Yemen		1991					0[47]	5.04

Table 5: List of wind firms

Manufacturing Firm	Country	Founding Year	Source
A-Power Energy	China	2003	`http://www.apowerenergy.com/EN/Info/enAboutUs.html`
Acciona	Italy	1991	`http://www.acciona-energia.com/about_us/the_company.aspx`
Alstom Power	France	1981	`http://www.alstom.com/power/renewables/wind/`
Bard	Germany	2007	`http://www.bard-offshore.de/en/company/bard-emden-energy1`
Blaaster	Norway	2007	`http://www.blaaster.no/?page_id=2`
Clipper	USA	2001	`http://clipperwind.com/designhistory.html`
Chiranijjeevi Wind Energy	India	1998	`http://cwel.in/about.html`
DDIS	France	2008	`http://www.ddiswt.com/Who-we-are`

[44] Source: `http://www.powerengineeringint.com/articles/mee/print/volume-7/issue-4/features/uae-seeks-broader-fuel-mix.html`
[45] Source: `http://www.reeep.org/index.php?id=9353&special=viewitem&cid=91`
[46] Source: `http://www.energici.com/energy-profiles/by-country/central-a-south-america-m-z/venezuela`
[47] Source: `http://www.energici.com/energy-profiles/by-country/middle-east/yemen`

Table 5: (continued)

Dongfang	China	1984	http://knol.google.com/k/wind-turbines/top-10-world-s-largest-wind-turbine/25fjwptfb1ke6/3#
Doosan	South Korea	2009	http://www.doosan.com/doosanheavybiz/en/services/green_energy/wind.page?
Enercon	Germany	1984	http://www.enercon.de/en-en/83.htm
EWT	Netherlands	2004	http://www.ewtinternational.com/?id=16
Fuhrleander	Germany	1991	http://www.fuhrlaender.de/en/company/history.html
Gamesa	Spain	1994	http://www.gamesa.es/en/gamesaen/history/start-of-the-wind-activity-1994-1999.html
Global Wind Power	Netherlands	2006	http://www.globalwindpower.nl/files/13/709_brochure_gwp.pdf
Goldwind	China	1986	http://www.goldwindglobal.com/web/about.do?action=timeline
Hewind	China	2002	http://www.hewind.com/eng/about.asp
Inox Wind	India	2006	http://www.inoxwind.com/about-us.html
IMPSA	Argentina	1990	http://www.impsa.com/en/aboutus/history/SitePages/1990.aspx
Jacobs	USA	1986	http://www.windturbine.net/
Kenersys	Germany	2007	http://www.kenersys.com/KENERSYS-Profile.23.0.html
Lagerway	Netherlands	1979	http://www.lagerweywind.nl/about-us/history/
Leitwind	Italy	2003	http://en.leitwind.com/Company/History

Table 5: (continued)

LM Wind Power	Denmark	2001	`http://www.lmwindpower.com/About/LMWP\%20Blades\%20in\%20brief/History.aspx`
M Torres	Spain	1998	`http://www.mtorres.es/default.asp?id=2&menu=01&idmenu=1&donde=8`
Nordex	Germany	1985	`http://www.nordex-online.com/en/company-career/history.html`
Nordic Windpower	USA	2007	`http://www.nordicwindpower.com/overview.html`
Northern Power Systems	USA	1974	`http://www.northernpower.com/about/company-history.php`
Norwin	Denmark	1982	`http://www.norwin.dk/`
Palmtree Power	South Africa	2005	`http://www.okhela.com/about.htm`
Pioneer Wincon	India	1996	`http://www.pioneerwincon.com/about.htm`
PowerWind	Germany	2006	`http://www.powerwind.de/en/company.html`
Quietrevolution	UK	2006	`http://www.quietrevolution.com/our-team.htm`
Redriven Power Inc.	Canada	2007	`http://www.redriven.ca/about-us/`
REpower	Germany	2001	`http://knol.google.com/k/wind-turbines/top-10-world-s-largest-wind-turbine/25fjwptfb1ke6/3#`
Sabaniroo	Iran	2000	`http://www.sabaniroo.co.ir/eng/index.asp`
STX Windpower	Netherlands	2009	`http://www.stxwind.com/nl/index/20-stx_windpower_bv`
Suzlon	India	1995	`http://suzlon.com/about_suzlon/l2.aspx?l1=1&l2=1`
Sway	Norway	2002	`http://sway.no/?page=165`

Table 5: (continued)

Turbowinds	Belgium	1985	http://www.turbowinds.com/
Unison	South Korea	1984	http://www.unison.co.kr/2009/Eng2/Company/History/History.asp?sYear=2000&eYear=1984&fpageNum=1&fsubNum=4
Vensys	Germany	2000	http://www.vensys.de/energy-en/unternehmen/historie.php
Vestas	Denmark	1979	http://www.vestas.com/en/about-vestas/history.aspx
W2E	Germany	2003	http://www.w2e-rostock.de/en/company
Windflow	New Zealand	2000	http://www.windflow.co.nz/about-windflow
Windtec	Austria	1995	http://www.windtec.at/about_amsc_windtec.html
Wind Technik Nord	Germany	1986	http://www.windtechniknord.de/html/eng/profile.htm
Winwind	Finland	2000	http://www.winwind.com/en/about-us/
WES18	Canada	1983	http://www.windenergysolutions.nl/index/8/history
Xemc Windpower	China	1995	http://www.xemc.com.cn/en/cooperation/coop_enter_wind.html
Xemc-Darwind	Netherlands	2009	http://www.xemc-darwind.com/index.php/news.html

List of Manufacturers Source: http://www.windenergydatabase.pl/index.php?option=com_content&view=article&id=8:medium-a-large-turbines&Itemid=10

Table 6: (continued)

Table 6: List of included industry associations

Industry Association	Founding Year	Source
Albania Energy Association	2011	http://knol.google.com/k/wind-turbines/wind-energy-associations-in-the-world/25fjwptfb1ke6/6#
Argentine Wind Energy Association	1996	http://www.argentinaeolica.org.ar/portal/index.php?option=com_content&task=view&id=2&Itemid=7
Austrian Wind Energy Association	1993	Personal correspondence
Flemish Wind Energy Association	1996	http://www.vwea.be/
Brazilian Wind Energy Association	1997	http://www.windpowermonthly.com/news/indepth/1022252/Interview-Brazilian-wind-industry-vice-president-Lauro-Fiuza/
Bulgarian Wind Power Association	2004	http://www.apeebg.org/index.php?option=com_content&view=article&id=51
Canadian Wind Energy Association	1984	http://www.canwea.ca/about/index_e.php
Chinese Wind Energy Association	1981	http://www.cwea.org.cn/intro/display_info.asp?cid=7
Wind Energy Association, Croatia	2005	http://www.hgk.hr/wps/portal/!ut/p/.cmd/cl/.l/hr?legacyWcmClippingUrl=http\%3A\%2F\%2Fhgk.biznet.hr\%2Fhgk\%2Ftekst3.php\%3Fa\%3Db\%26page\%3Dtekst\%26udruzenja\%3D1\%bb26id\%3D1796\%26kid\%3D1472\%26skid\%3D1977
Cyprus Wind Energy Association		
Czech Society for Wind Energy	1994	http://www.csve.cz/en/clanky/proc-se-stat-clenem-csve-/32

Table 6: (continued)

Danish Wind Turbine Owners Association	1978	http://www.wind-energy-market.com/en/companies-and-addresses/details/details/adr/danish-wind-turbine-owners-association-2/
Egyptian Wind Energy Association		
Estonian Wind Power Association	2001	http://www.tuuleenergia.ee/en/ewpa/
Finnish Wind Power Association	1988	http://www.tuulivoimayhdistys.fi/yhdistyksesta
France Energie Eolienne	1996	http://fee.asso.fr/qui_sommes_nous
German Wind Energy Association	1996	http://www.wind-energie.de/verband/aufgaben-und-ziele
Hellenic Wind Energy Association	1991	http://www.eletaen.gr/company
Hungarian Wind Energy Scientific Association	1999	http://www.google.se/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CFIQFjAA&url=http\%3A\%2F\%2Fwww.erec.org\%2Ffileadmin\%2Ferec_docs\%2FProjcet_Documents\%2FRESTMAC\%2FHWEA_HungaryEN_.pps&ei=8TzPT5e1L6qm4gSNhJmFDA&usg=AFQjCNEMXXhA_T3FhEMd0uIaAutRZfqlaA&sig2=zAU0OQJYKFoXrYzZgmauZA
Indian Wind Energy Association	2002	http://www.inwea.org/aboutinwea.htm
Irish Wind Energy Association	1993	http://www.iwea.com/index.cfm/page/iweacouncil
Israel Wind Energy Association	2009	http://www.renewable.org.il/he-il/english.htm
Italian Wind Energy Association	2002	http://www.anev.org/?page_id=18
Japan Wind Energy Association	2001	http://jwpa.jp/englishsite/jwpa/index.html
Korean Wind Energy Association	2007	http://www.kweia.or.kr/eng/sub02.asp
Latvian Wind Energy Association		

Table 6: (continued)

Lithuanian Wind Energy Association	2002	http://lwea.lt/portal/index.php?option=com_content&view=article&id=52&Itemid=67&lang=en
Mexican Wind Energy Association	2005	http://www.amdee.org/Amdee/nosotros.htm
Mongolian Wind Energy Association	2008	http://www.monwea.org/index.php?none=55&newsid=203
Netherlands Wind Energy Association	2005	http://www.nwea.nl/geschiedenis-ontstaan
Norwegian Wind Energy Association	2006	http://norwea.no/om-norwea.aspx
Polish Wind Energy Society	1999	http://www.pwea.pl/who_are_we.htm
Romanian Wind Energy Association		
Russian Association of Wind Industry	2003	http://rawi.ru/en/events/press-releases.php
Slovak Association for Wind Energy	1999	http://www.save.szm.com/
South African Wind Energy Association	1998	http://www.sawea.org.za/index.php?option=com_content&view=article&id=5&Itemid=2
Spanish Renewable Energy Association	1987	http://www.appa.es/02appa/02asociacion.php
Swedish Wind Energy Association	1986	http://www.svensk-vindkraft.org/index.php?option=com_content&task=view&id=45&Itemid=60
Suisse Eole	1998	http://www.suisse-eole.ch/suisse-eole/qui-sommes-nous.html
Turkish Wind Energy Association	1992	http://www.ruzgarenerjisibirligi.org.tr/
Ukrainian Wind Energy Association	2008	http://www.uwea.com.ua/about.php
British Small Wind Association, RenewableUK	1978	http://www.bwea.com/about/index.html
American Wind Energy Association	1974	http://en.wikipedia.org/wiki/American_Wind_Energy_Association#cite_note-0
Venezuelan Wind Energy Association	2009	http://www.aveol.org.ve/index.html

Table 7: List of included national policies

Country	Policy	Type	Year
Afghanistan	Afghan Clean Energy Program [48]	Direct subsidy	2009
Algeria	Law 04-90 on Renewable Energy Promotion in the Framework of Sustainable Development [49]	Direct subsidy	2004
Argentina	Law no. 25019 on the promotion of solar and wind energy	Direct subsidy	1999
Australia	Safeguarding the Future: Australia's Response to Climate Change	Renewable portfolio standard (RPS)	1998
Austria	Renewable Energy Targets	RPS	2000
Belarus	Feed-in tariffs for renewable energy	Feed-in Tariff (FIT)	1994
Belgium	Flemish agency for the rational use of energy subsidy	FIT	1997
Bolivia	Electrificacion Rural con Energias Renovables a traves del Proceso de Participacion Popular	Rural electrification, Direct subsidy	2000
Brazil	Program of incentives for alternative electricity sources	RPS, Direct subsidy	2002
Bulgaria	Renewable and alternative energy sources and biofuels act	FIT	2009
Canada	Income tax act - accelerated capital cost allowance	Tax advantage	1994
Chile	Invest Chile Project	Direct subsidy	2005
China	Brightness Program	Rural electrification, Direct subsidy	1996
Croatia	National energy program [50]	Installation target	1997
Cyprus	plan for the promotion of renewable energy sources, 2002-2010 [51]	Direct subsidy	2010

[48] http://www.afghaneic.org/acep.php

[49] Except where otherwise noted, all policies from IEA Renewable Energy Policies and Measures Database, www.iea.org/textbase/pm/index.html

[50] http://ws2-23.myloadspring.com/sites/renew/countries/croatia/profile.aspx#Policy

[51] http://www.cie.org.cy/menuGr/pdf/APE-EXE/presentation_Kassinis_14.05.09.pdf

Table 7: (continued)

Czech Republic	National program for economical energy management and use of renewable and secondary energy resources	Energy roadmap, Direct subsidy	2001
Denmark	Technical certification scheme for the design, manufacture, and installation of wind turbines	Certification	1980
Egypt	New National Renewable Energy Strategy	RPS	2007
Estonia	Energy Act	FIT	1998
Finland	Wind Power Programme	Installation target	1993
France	Wind Energy Programme	Installation target	1996
Germany	Electricity Feed-in Law of 1991	FIT	1991
Ghana	Tax and Duty Exemptions	Tax advantage	1998
Greece	Siting of wind turbines	Regulation	1987
Hungary	Energy Savings Action Plan	Installation target	1996
India	Government assistance for wind power development	Tax advantage	2002
Indonesia	National energy blueprint	Installation target	2005
Iran	Renewable energy development act [52]	FIT	2001
Ireland	Business expansion scheme tax relief	Tax advantage	1984
Israel	Renewable energy targets	Installation target	2002
Italy	Measures to promote distributed generation and market liberalization	Regulation	1991
Japan	New renewable energy target	Installation target	1996
Jordan	National energy efficiency strategy	Installation target	2005
Kenya	Feed-in tariff for renewable energy resource generated electricity	FIT	2008
South Korea	Renewable energy demonstration and deployment loan subsidy	Tax advantage	1987
Latvia	Feed-in tariff [53]	FIT	1995
Libya	Law 426 to create the renewable energy authority of Libya	Installation target	2007
Lithuania	Law on energy of the Republic of Lithuania	FIT	2002

[52] http://www.wupperinst.org/uploads/tx_wiprojekt/Iran6_WP1-final-summary.pdf

[53] http://www.windenergy.lv/DOC/wind_energy_eng_final.pdf

Table 7: (continued)

Luxembourg	Feed-in tariffs for renewable energy sources and cogeneration	FIT	1994
Mexico	Grid interconnection contract for renewable energy	Direct subsidy	2001
Mongolia	Renewable energy law of Mongolia [54]	FIT	2007
Morocco	Renewable energy development law 13.09	Installation target	2009
Netherlands	Regulatory energy tax	Tax advantage	1996
New Zealand	Energy efficiency and conservation act 2000	Installation target	2000
Nigeria	Nigeria renewable energy master plan [55]	Installation target	2006
Norway	White paper on energy policy	Installation target	1999
Peru	Law 1002 on the promotion of electricity from renewable energy sources	FIT	2008
Philippines	Investment priorities plan	Tax advantage	2002
Poland	Obligation for power purchase from renewable sources	FIT	2005
Portugal	Portaria no.383	Direct subsidy	2000
Russia	State policy guidelines for promoting renewable energy in the power sector	FIT	2009
Singapore	Innovation for environmental sustainability fund	Direct subsidy	2001
Slovakia	Act on regulation in network industries	FIT	2001
Slovenia	Eco-fund	Tax advantage	2000
South Africa	Renewable energy subsidies - DME	Direct subsidy	2005
Spain	General electricity law 54	FIT	1997
Sweden	Environmental bonus for wind power	Tax advantage	1994
Switzerland	Energy decree	FIT	1991
Tanzania	2010 electricity rules	FIT	2010
Thailand	Energy conservation program	Direct subsidy	1992
Tunisia	Law and decree on energy conservation and renewable energy	Tax advantage	2005
Turkey	Electricity market licensing regulation	Direct subsidy	2001

[54] `http://www.wind-works.org/FeedLaws/Mongolia/MongolianRenewableEnergyLaw.pdf`

[55] `http://www.worldfuturecouncil.org/fileadmin/user_upload/Presentations/Nigeria_RENEWABLE_ENERGY_MASTERPLAN.pdf`

Table 7: (continued)

Uganda	Renewable energy feed-in tariff	FIT	2011
Ukraine	Programme of state support for non-traditional and renewable energy sources	Installation target	1997
United Kingdom	Reduced VAT for energy saving material	Tax advantage	2000
United States	Energy tax act of 1978	Tax advantage	1978

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