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It Should Be a Breeze: Harnessing the Potential of Open Trade and Investment Flows in the Wind Energy Industry

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Abstract

This working paper maps out the structure and value chains of the wind industry, analyzes the wind industry's increasing global integration via cross-border trade and investment flows, and offers recommendations to policymakers for the design of investment and trade policies to help realize wind energy's potential. We find that demand for wind energy through long-term government support policies creates the basis for local supply of wind capital equipment and services and associated local job creation; policies that put a price on carbon will further help to make wind energy more competitive and increase the overall demand for turbines and equipment. Cross-border investment rather than trade is the dominant mode of the wind industry's global integration. Principal barriers to global integration are nontariff trade barriers and formal and informal barriers that distort firms' investment decisions. These include local content requirements, divergent national industrial standards and licensing demands, and in particular political expectations. Intellectual property accounts for only a very small part of cost in the wind industry, and wind technology is widely available for licensing. Intellectual property rights are correspondingly not a major impediment for market participation. Credible long-term commitments coupled with a reduction or elimination of existing barriers to cross-border trade and investment are necessary to harness the full potential of global integration in reducing wind industry prices and increase worldwide deployment of wind energy.

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INTRODUCTION

The political debate concerning climate change and global trade and investment flows has increasingly taken on a defensive posture in the United States and other developed countries. The spotlight has been on the competitiveness of energy-intensive industries and potential border adjustment mechanisms to prevent carbon leakage, as well as on the need to grow and protect industries that will gain from a low-carbon future and create millions of new "green jobs" at home.[1] This paper analyzes the global wind power industry in light of the latter debate and shows that global integration—broadly defined as increasing cross-border trade and investment flows[2]—can make a strong positive contribution in the form of green technology cost reductions and innovation while still creating predominantly local jobs. As such, national trade and investment policies that promote increased global integration of the wind industry are a powerful ally in the fight against climate change.

Our analysis starts with a brief summary of current and future global demand for wind turbines and the role of government support in this demand picture. Next, we show how the wind energy sector is developing into a truly global industry characterized by high levels of growth and competition and how this process is increasingly driven by cross-border investment rather than trade. Then we map out the globalization potential of different components in the value chain and analyze existing barriers to further global integration. Finally, we discuss the distributional consequences of greater globalization and especially the outlook for green job creation along the wind value chain, before we conclude with a set of policy recommendations.

Our principal findings are:

1. Local demand creation draws in local production. Demand for wind energy through long-term government support policies creates the basis for local supply of wind capital equipment and services and associated local job creation; policies that put a price on carbon will further help to make wind more competitive and increase the overall demand for turbines and equipment.
2. Cross-border investment rather than trade is the dominant mode of global integration. Standard international trade in wind energy equipment is relatively small and declining. Instead, foreign direct investment (FDI) flows dominate the global integration of the wind sector, and the cost structure of the wind industry favors the emergence of regional production hubs in markets of sufficient size.

1. See, for instance, the Waxman-Markey bill as passed by the US House of Representatives, sections 761-769, at http://thomas.loc.gov; the Obama 2008 campaign promise to create 5 million new green jobs, at www.barackobama.com; or President Obama's comments in Newton, Iowa, April 22, 2009, at www.whitehouse.gov.

2. Following Slaughter and Scheve (2001), we will take "global integration" to mean the increased integration of product and factor markets across countries through cross-border trade and foreign direct investment (FDI), i.e., the increase in cross-border flows of goods and services, as well as capital linked to multinational companies. Analysis of increased global flows of people (immigration) and financial capital (portfolio investment flows) are outside this analysis. Furthermore, we will follow Bernard, Jensen, and Schott (2005) in assuming that FDI reflects a deeper version of global integration than does cross-border trade.

3. Abolishing trade tariffs will have limited effects on the wind industry. Principal barriers to global integration are not at-the-border tariffs but rather several nontariff trade barriers and formal and informal barriers that distort firms' investment decisions.
4. Intellectual property rights (IPRs) are currently not restricting firms' access to wind power equipment markets. Intellectual property plays only a very limited role in the cost structures of the wind industry, and technology is widely available for licensing. IPRs therefore cannot be considered a major impediment for market participation for firms from both developed and developing countries.
5. A highly globalized wind industry will create jobs locally. Wind energy is a generally more labor-intensive source of electricity supply compared with fossil fuel generation. Due to its specific characteristics, a globalized wind industry will still create lasting and highly localized employment opportunities.

GLOBAL DEMAND AND THE ROLE OF GOVERNMENT SUPPORT

Global demand for installed wind turbine capacity has grown fast over the past decade. North America and Asia, most notably China, have recently developed into large markets alongside the historically dominant European market. The demand is mostly driven by government support schemes and not by cost considerations based on market prices and geographical conditions. However, the combination of further cost declines for wind turbine equipment and changing pricing for power generation from fossil fuels are expected to increase the competitiveness and thus the future demand for wind energy installations.

Global Demand Picture

Wind is among the most time-tested renewable electricity-generating technologies, with a deployment history stretching back to the early 1980s,[3] and today around 130,000 wind turbines are in operation or under construction.[4] Wind power has experienced explosive global growth especially in recent years, expanding globally installed capacity 25-fold from 1995 to a total of more than 120GW by the end of 2008.[5]

In regional comparison, the European market has been dominant since the early 1990s, accounting for more than 70 percent of total global installed capacity until 2003–04 (table 1). However, both Asian and North American markets grew very rapidly between 2003 and 2008, so that by 2008 all three regional markets were growing at an approximately equal speed of 8,500MW to 9,000MW of new

3. BTM Consult (2009, figure 2.1), DoE (2009, figure 1). This working paper will not cover small and micro wind turbines and off-grid wind.

4. Turbine data are from BTM Consult (2009, 18).

5. Data are from GWEC (2005, 2009a). These data take into account annual decommissioning of wind turbines.

installed capacity annually.[6] While regional markets outside Asia, Europe, and North America continue to play only a marginal role in total global demand, lower and especially upper middle income countries are increasingly becoming important market participants. By end-2008, they together accounted for over one-third of new installed capacity, with China and India making up the lion's share. As such, large-scale power production from wind energy is no longer an energy source tapped only by rich countries.[7]

Offshore wind turbines are the technologically most advanced product of the wind industry and are also the market segment with the highest growth potential (BTM Consult 2009). Analyzing this segment separately reveals a somewhat different global picture. Total global installed offshore wind turbine capacity by the end of 2008 was a mere 1,471MW, or just over 1 percent of total (on and offshore) installed wind capacity in 2008 (EWEA 2009a). Unlike the onshore market, all commercially operating offshore wind turbines were at the end of 2008 concentrated in just a few European countries around the North Sea.[8] Total world offshore capacity today thus roughly equals total (on and offshore) installed capacity in the world around 1990 (EWEA 2004). So far no offshore wind power has been installed in the United States, with BTM Consult (2009) projecting the first by only 2011, while a 100MW pilot project has been initiated in China (BTM Consult 2009, 60–61; DoE 2009, 11). In short, and in contrast to the rapidly globalizing onshore wind market, offshore wind energy looks to remain an almost exclusively European market.[9]

While the global economic crisis has dampened demand growth in some countries, noticeably the United States, rapid global growth at between 20 and 25 percent annually is expected to continue in the short and medium terms (table 2).[10] The European, North American, and Asian markets for wind turbines are expected to continue to grow at roughly the same rate as in 2008, with the European market

6. This shift away from Europe is equally evident in cumulative installed wind turbine capacity, with Europe's share dropping from almost three-quarters to just over half of global capacity from 2003 to 2008. Europe's share of global installed wind turbine capacity by end-2008 had thus fallen back to its level in the mid-1990s (EWEA 2002). Prior to this time, the United States hosted by far the largest share of world's installed wind power capacity, with California alone accounting for 90 percent of global capacity in 1986 and Europe accounting for just 25 percent as late as 1990.

7. By the term "large-scale power production" is meant commercial power production from wind turbines aimed at selling power to the standard electricity grid. Small and micro wind turbines, usually intended for off-grid self-sufficiency purposes at remote locations, have for a long time been produced and widely used in many developing countries too. See AWEA (2009a).

8. Principally in the United Kingdom and Denmark, with smaller capacity in the Netherlands, Germany, Ireland, Belgium, Sweden, and Finland. In reality, the commercial offshore wind market is even more concentrated, as installed capacity in several European countries remains at near-shore locations for R&D and testing purposes. See BTM Consult (2009, 15).

9. This state of affairs seems likely to persist for some time, as even the "ideal scenario" in DoE (2008) for achieving 20 percent of US power from wind energy by 2030 does not foresee significant US offshore wind power capacity before 2020. This reflects the ample onshore wind resources available in the United States, relative to Europe and Asia.

10. For the situation of wind energy financing in the United States, see AWEA (2009d); projections in table 2 are from BTM Consult (2009); see also EWEA (2009b) and GWEC (2009b).

expected to shift increasingly to the offshore segment. Longer-term projections for the wind turbine market also remain bullish, based on clear political commitments in the main markets to continue the expansion of the sector (table 2).

The 2009–13 projections in table 2 indicate that actual wind power market growth is on track (again) to surpass the growth targets included in US, EU, and Chinese official scenarios for rapid wind sector expansion in the coming years.[11]

Government Support as Main Driver of Demand

The global demand for wind turbines is principally driven not by the cost competitiveness of wind power but by revenue-side considerations, in particular the availability of government support measures for renewable energy sources. The global picture of wind turbine installations shows that demand closely follows the availability of subsidies and other government incentives and to a lesser extent other variables like the quality of wind speed or the availability of appropriate infrastructure.[12] Such support measures come in several categories and are implemented at all levels of government. They can be in the form of direct financial support to or requirements for renewable energy production/investments. Or they can be supporting renewable energy indirectly, for instance, by putting a price on carbon emissions across energy sources. The most frequently used types are described in box 1.

Governments have varied preferences with respect to individual support measures,[13] but most policymakers have at some point come to accept the necessity of providing financial support to promote the demand for wind energy. In many countries, particularly in Europe, the most widely used policy tools have been renewable portfolio standards (RPS) and feed-in tariffs (FITs). While a heated debate continues as to which of these approaches is preferable,[14] they have one important point in common: The government creates a legal framework but does not directly provide a subsidy. Instead, utilities pass through the additional costs of renewable power and spread it out across all power consumers.

11. DoE (2008, figure 1-4) indicates an annual US target of approximately 10GW of installed capacity in only 2014. EWEA (2008, 25ff) shows how European actual market developments have surpassed every European Commission future sector targets since 1997. BTM Consult (2009, 54) describes how the current National Development and Reform Commission 2010 target for Chinese wind energy has already been reached.

12. This illustrates the examples of Germany, which is one of the leading wind power nations despite its comparably poor wind speed, and China, where an estimated one-third of all installed turbine capacity is not connected to the grid due to lacking grid capacities.

13. The International Energy Agency's database for Global Renewable Energy Policies and Measures at www.iea.org lists 532 different country policy measures promoting wind and/or multiple renewable energy sources as of June 2009. See also Ragwitz et al. (2007).

14. Proponents of FITs argue that they provide more predictability to investors and can deliver a well-targeted support by providing different rates to different technologies. On the other hand, it is argued in favor of RPS that they provide utilities more flexibility in meeting a set target in the economically most efficient way. Empirical evidence from the European Union suggests that deployment in countries using a FIT has been faster and, surprisingly, the premium paid per kWh under FIT systems was lower than the price of certificates in RPS systems. See Morthorst et al. (2009).

Box 1 Government policies to support renewable energy sources[1]

Direct Renewable Financial Support Measures

- investment incentives, usually in the form of direct subsidies, soft loans and tax credits;
- generation incentives, either directly provided by the government, usually in the form of tax credits or mandated by the government through legislation requiring utilities and grid operators to accept renewable power into their grid and pay a fixed price for it. Such legislation provides certainty to generators of renewable/wind power that they will receive a fixed feed-in tariff (FIT) or a fixed premium above the market price for electricity. Directly paying for the FIT through all consumers' power bills has the advantage that such a program does not require direct government budget appropriations. Gradually reducing FITs after a given date can further serve to maintain the incentives of wind turbine producers to reduce power production costs for newly installed turbines.

Direct Renewable Market Penetration Requirements

- tradable certificate systems (also known as renewable portfolio standards [RPS]), in which different participants of the power supply chain (generators, utilities, grid operators, or retailers) are obliged to supply/purchase a given percentage of electricity from eligible renewable sources;[2]
- tendering/bidding systems: calls for tender are launched for specified amounts of renewable energy/production capacity with contract winners receiving a guaranteed price for a specified period of time.

Indirect Renewable Support Measures

- introduction of environmental (including CO_2) taxes on power produced from non-renewable sources;
- compulsory cap and trade systems for CO_2 emitters covering the power-generating sectors, with the strongest and most efficient incentives created in systems with full auctioning of permits.

Broader Renewable Energy Enabling Measures

- regulatory promotion, for instance, facilitated site planning and noise and visual impairment requirements that strike the right balance between addressing public concerns and eliminating unnecessary regulatory obstacles;
- public investments in smart grid technology to enable large-scale power supply from variable production rate renewable power source.[3]

1. For an elaboration, see Morthorst et al. (2009).

2. Certificates can usually be obtained either by producing or purchasing the required renewable power itself or by purchasing only the renewable energy certificates independently of the underlying power.

3. This would, for instance, include the smart grid investment spending announced by the Obama administration on October 27, 2009, available at www.whitehouse.gov.

Direct financial support by the government has also been used, particularly in the United States, which first introduced a federal production tax credit (PTC)[15] with the 1992 Energy Policy Act, and the impact of direct financial support on new investment levels has since been critical, as table 3 with data from four leading wind power markets for 1996–2008 illustrates. Table 3 shows how the PTC initially did little to spur new investment in large-scale US wind energy, but once investment picked up in 1998, the existence of a PTC became critical to continued growth. In years when Congress allowed the PTC to expire (1999, 2001, and 2003) new wind investments subsequently collapsed. The same pattern is found in Denmark, where the market fell flat following the expiry of the most generous government financial support measures in 2003. Meanwhile, large wind markets with stable long-term financial support mechanisms in place, such as Germany and Spain, have seen much more constant market expansions.[16]

COST TRENDS AND COMPETITIVENESS OF WIND POWER

The wind energy sector has historically seen steep industry learning curves and corresponding declining average project costs. During the early years of the (onshore) wind industry in the 1980s and 1990s, industry productivity rose rapidly[17] and average project costs for installed capacity declined from $3.5 million to $4.5 million/MW in the early 1980s to between $1 million and $1.5 million/MW by 2001–04.[18]

However, during the 2004–08 period, the historical declining trend in installed project costs in the wind industry inverted and average total project costs instead rose by up to 50 to 80 percent (BTM Consult 2008a and DoE 2009). This change was driven partly by supply constraints and partly by rapidly rising commodity prices. The recent cost increase in the wind industry mirrored the surge in capital costs across different power generation technologies during this period.[19] The fact that other sources of energy

15. The United States typically relies on tax credits as an instrument of government financial support, while, for instance, European countries usually rely on direct financial transfers from the government. Assuming recipients pay some taxes, the financial impact of a production tax credit (PTC) and a guaranteed FIT from the government is similar. The early growth of US wind power in California in the 1980s was also based upon state and federal investment tax credits and government guaranteed prices for wind-power. See DoE (2009).

16. See IEA database (see footnote 13) and BTM Consult (2008a, 2009).

17. Wind industry so-called learning rates were as high as 14 to 15 percent annually. The learning rate (and its inverse the progress ratio) is a standard tool for understanding long-term cost trends and relates cumulative installation/production and associated costs. For every doubling of cumulative installed capacity/production, the learning rate indicates the associated reduction in costs. See Arrow (1962), Boston Consulting Group (1972), and Abell and Hammond (1979). For learning rate estimates for the wind industry, see DoE (2009).

18. Estimates are for the US market expressed in 2008 dollars (DoE 2009, 34). Estimates in Neij (2003), Neij et al. (2006), and data in IEA (2008b) suggest roughly corresponding cost trends in European markets.

19. The IHS-CERA Power Capital Costs Index (PCCI 2000 = 100), excluding nuclear, also rose roughly 50 percent from about 120 in 2004 to 182 by 2008Q1. See IHS Inc., North American Power Generation Construction Costs Rise 27 Percent in 12 Months to New High*,* news release, February 14, 2008, available at http://energy.ihs.com. See also Fox-Penner, Chubka, and Earle (2008).

also became more expensive can partly explain why the demand for wind power did not fall. However, the sector even continued to expand rapidly. It is striking to see how global installed capacity tripled from 2003 to 2008—matching over this period average annual global growth rates in installed capacity of 26 percent—during a period in which industry cost rose significantly. This was possible only because of continued political commitment to developing the sector.

Future Competitiveness of Wind Power

Governments' targeted direct financial support and explicit policy promotion of wind power (and other renewable energy sources) are, when offered on a stable and sustained long-term basis, likely to continue to play an important role for future wind industry growth. However, wind energy is likely to benefit increasingly from indirect policy measures, too, and begin to compete on an increasingly commercial basis with other sources of power supply.

Comparative estimates suggest that the most cost efficient wind power—onshore production in coastal (i.e., good wind) areas—becomes competitive with traditionally generated power even at moderate fossil fuel prices once environmental, security of supply, and other usually nonmonetized externalities are accounted for.[20] Imposing a price on carbon emissions is one important way of internalizing some of these externalities. The increasing use of policies imposing a price on carbon emissions will therefore be a major additional growth driver for wind energy in the future. Similarly, the establishment of official renewable energy targets in the United States, European Union, China, and other countries[21] and the resulting expansion of FITs or RPS rules in power supply will continue to offer strong demand support for wind energy. A wind industry relying increasingly on demand support from, for instance, economy-wide and relatively stable carbon pricing would face far less political risk to its demand side (i.e., the risk that direct government financial support be suddenly withdrawn) and hence present potential investors with a more stable long-term investment outlook. This stabilizing effect would likely provide a powerful independent boost to the demand for wind energy and allow manufacturers to further expand economies of scale.

In the future, the cost competitiveness of the wind sector when compared with other sources of energy supply will therefore become more important for the growth of the industry. An analysis of the current cost structure of wind investments provides insights into the determinants of the future

20. See IEA (2008b), Lazard (2008), Morthorst (2009), McKinsey and Company (2008), and the IEA Renewable Energy Costs and Benefits for Society (RECaBS) model available at http://recabs.iea-retd.org.

21. The DoE (2009) lists 29 US states with mandatory RPSs in place in 2008, while all federal climate change legislation considered by Congress recently (Bingaman energy bill, HR 890 bill sponsored by Rep. Edward Markey, Waxman-Markey bill, and S 433 bill sponsored by Senator Tom Udall) all include US federal RPS provisions. The European Union has an agreed goal of an overall 20 percent renewable energy (differentiated national goals ranging from 10 to 49 percent) consumption by 2020, while China in 2007 set the target of 15 percent of primary energy from renewable sources by 2020. See Ren21 (2009) for a complete list of global RPS rules in place in early 2009.

competitiveness of wind power. As illustrated in table 4, wind is a highly capital intensive way to produce power, with 75 to 80 percent of total lifetime production costs made up of upfront fixed capital costs—the turbine itself, foundations, electrical installations, grid connections and control systems, wind mapping/site consulting, and financing.[22] On the one hand, this capital intensity raises large upfront project financing requirements. On the other hand, it reflects one of the most appealing aspects of wind energy: very low variable costs. Unlike with natural gas or coal power production (where fuel costs can make up the majority of total project life costs[23]), variable fuel input costs for wind are zero, since the wind blows for free.[24] Instead, variable costs for wind energy projects are only operation and maintenance (O&M) costs, consisting of such things as insurance, servicing, repair/spare parts, and administrative costs. Sample surveys of existing wind farms in the United States and Europe suggest that average annual O&M costs account for roughly 1 percent of total project costs, thus accumulating into about 20 to 23 percent over the standard lifetime of a wind turbine.

Correspondingly, major future cost improvements for wind industry investments would have to be concentrated in the dominant capital equipment cost segment. Historically, global integration of manufacturing sectors has driven down cost through facilitation of economies of scale, increased competition, technological innovation, and just-in-time production techniques with lean global supply chains.[25] When asked about the outlook for the wind industry investment breakdown, interviewed industry experts generally expressed the belief that the relative cost share of fixed upfront capital should decline as technology learning, global integration of supply chains, and increased global competition yield better turbine design and cheaper components.

At the same time, however, at least three trends in the wind industry might cause wind industry costs to rise in the future. First, offshore wind, which gains importance particularly in Europe, entails between 50 to 100 percent higher capital and variable O&M costs compared with onshore wind turbines, due to more adverse conditions.[26] Second, some concerns exist regarding the future trends of wind O&M

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22. See Lemming, Morthorst, and Clausen (2008) and the National Renewable Energy Laboratory's (NREL) Job and Economic Development Impact (JEDI) data model at www.nrel.gov for detailed estimates.

23. For instance, NREL's data model for natural gas, JEDI Natural Gas Model, available at www.nrel.gov, indicates that annual variable fuel costs might reach 50 percent of total fixed construction costs.

24. The stability of variable costs for wind energy can be an important hedge for fluctuating fossil fuel costs, even if part of a diversified power production portfolio across different sectors. See Awerbuch (2003).

25. The immense literature on this topic is too big to do justice here. See Wolf (2004) and Bhagwati (2004) for detailed analysis of this topic.

26. See EWEA (2009a). Particularly in countries with substantial onshore "good wind areas," such as the United States and China, this offshore cost disadvantage may remain prohibitive in the near to medium term. The United States has large areas in the midwestern states well suited for wind energy, as does China in its Inner Mongolia province. Both relatively remote locations far away from costal population and economic centers, however, require significant power grid investments.

costs, as the rapid scaling up of average turbine sizes in newly installed capacity[27] means that no estimates for late life O&M costs are available yet for the vast majority of globally installed capacity.[28] Third, as power cannot yet be economically stored and wind energy is a variable producer, introducing large shares of wind power into an electricity system increases total infrastructure costs of securing constant grid balancing.

On balance, industry analysts agree that with continued global integration of wind power manufacturing and related continued steep wind industry learning curves, future capital cost declines will dominate construction, O&M, and grid connectivity cost trends, and the long-term decline in total wind industry investment costs seen until around 2004 will resume. Maintaining strong policy support for carbon pricing, other renewable energy support measures, and trade and investment policies that promote global industry integration will be crucial for this scenario to unfold.

STRUCTURE AND GLOBAL INTEGRATION OF THE WIND INDUSTRY

Global integration is a powerful force that can be harnessed to reduce the cost of wind technologies by increasing economies of scale, fostering competition, and encouraging innovation. The wind energy industry is in the midst of a process toward deeper global integration, with multinational company investment flows (FDI) gradually replacing standard cross-border trade as dominant vehicle of globalization. Regional markets and production hubs are emerging, and a growing number of wind turbine producers from developing countries participate in the market as global suppliers.

Industry Structure

As table 4 demonstrates, wind turbine investments can essentially be broken down into two main categories: capital equipment (i.e., turbines) and everything else. Similarly, two distinct, but overlapping, “value chains” exist in the wind industry: the wind turbine production value chain and the wind power production value chain (table 5).

Today’s global wind power equipment industry is relatively concentrated, with the top 10 turbine manufacturers accounting for 85 percent of the market in 2008, albeit reflecting the rapid growth of new entrants in a booming market; this is a decline from a top 10 market share of 95 percent upto 2006

27. BTM Consult (2009, tables 2.6 and 2.7) shows the average size of newly installed wind turbines in 2008 to be between 1 to 2.3MW in the world’s top eight markets, which is two to three times bigger than the cumulative average for installed wind turbines in these same markets. In 2008 the global average size for installed wind turbines for the first time passed 1.5MW (BTM Consult 2009, 30).

28. At the same time, as sophisticated large-scale utility-size operators of windmill parks increasingly dominate the wind energy markets, operation and maintenance (O&M) costs become more operationally important as a cost driver. See Vestas (2009), Siemens (2009), and GE Energy (2009) for examples of leading wind turbine producers explicitly emphasizing the reduction in O&M costs for their most recent products.

(BTM Consult 2009, 29). Figure 1 demonstrates the 2008 market presence of the world's 15 largest wind turbine producers, accounting for 95 percent of supplied capacity in 2008.

European firms dominate the world's wind turbine market, with eight of the top 15 firms and close to 60 percent world market share. At the same time, the bottom left corner of figure 1 shows that several Chinese companies, supplying only their domestic market, are capitalizing on the strong growth in installed wind power capacity in China. Similarly, recent years' strong growth in the US market has benefited local producer GE Wind, allowing it to almost eclipse global market leader Vestas in terms of global market share in 2008, while relying almost exclusively (90 percent) on its domestic US market. Figure 1 also indicates the importance of a large domestic market for wind turbine producers, as 13 of the top 15 companies' origin is in the five countries with the most installed cumulative capacity in 2008 (in the order of United States, Germany, Spain, China, and India).[29] Only Mitsubishi of Japan and global market leader Vestas do not have large domestic markets, although in the case of Vestas, the company has evidently benefited from Denmark's early embrace of wind power, which made this country the fourth-largest wind power market in the world in terms of installed capacity as late as 2004.

Developing nations' firms—with four out of the top 15—are clearly present among globally leading wind energy firms. All of these four companies come from either China or India but have pursued very different global growth strategies. While Chinese wind turbine manufacturers have so far relied almost exclusively on their domestic market's potential for growth, India's Suzlon has both dominated its domestic market for wind power and expanded its global reach through investments in other countries. The company has both invested in new production facilities abroad ("greenfield investments") and acquired a series of foreign competitors (cross-border M&A transactions).[30] The principal encouraging point for the developing world, however, is that developing countries tend to follow the same broad pattern as developed countries with respect to wind market participants. Create a sufficiently large domestic market (as in China and India), and domestic wind turbine suppliers emerge. As in the early Californian and European pioneers, in the developing world, too, today it is local demand creation that matters most.

Leading wind turbine producers do not independently produce every part of their turbines but rely on an extensive network of external suppliers for a big share of the up to 8,000 individual components

29. Ecotecnia of Spain was in 2007 purchased by Alstrom of France, while Suzlon acquired a controlling stake in REPower in 2008. Moreover, 3,900 of Siemens Wind 5,000 employees are in Denmark following Siemens' acquisition of Danish wind turbine producer Bonus Energy A/S in 2004, while also Suzlon's international business headquarter is located in Denmark (source: company websites).

30. In 2006 the company acquired a controlling stake in Hansen Transmissions of Belgium, the world's second largest gearbox manufacturer; in 2007 it acquired REPower of Germany (source: Suzlon website, *www.suzlon.com*). This represents an example of the trend of FDI flowing "upwards" from developing to developed countries identified in Mattoo and Subramanian (2009).

that a standard utility-scale wind turbine consists of.[31] As such, the industry's sourcing strategies and supply chains, summarized in table 5, are of critical importance. Some segments of the industry supply chain, like blades and gearboxes, are characterized by large degrees of vertical integration and direct control and ownership of the turbine manufacturer, while for other segments, such as towers and bearings, turbine producers rely overwhelmingly on external producers (table 5).

Interviewed industry experts identified a common need among globally leading firms to ensure the quality of their components and two different supply chain strategies being used to achieve this: Some firms have moved towards increased vertical integration, producing their own components, which guarantees supply and enhances quality control over key components. Others have increasingly relied on the rapidly improving supply capacity from smaller external suppliers, especially in the emerging non-European production hubs in the United States and China. In the latter case, the leading wind turbine producers demand that local external suppliers produce according to world industry standards.

The wind power production value chain (captured at the bottom "downstream" part of table 5) consists of the planning, construction, and operation of grid connected wind parks. Unlike the manufacturing supply chain of turbine production, wind power production consists mainly of related services, such as assessment of suitable wind park sites, wind investment financing, logistics, construction services, and the subsequent O&M services and power sales.

The direct involvement of leading turbine producers in the wind power production supply chain varies from project to project. Some transactions are on an "everything included basis," such that the turbine producer will also be responsible for the planning, deployment, and subsequent O&M servicing. However, as the wind power industry customer base has increasingly become large established utilities, the wind power production supply chain is gradually being taken over by these utilities, which often possess the required in-house capacity for managing the complete process. The 15 largest global utilities, dominated by European, US, and Chinese players, in 2008 owned approximately 36 percent of all installed wind production capacity.[32] With the European shift toward offshore wind power and the associated increase in financing requirements, as well as the growing use of portfolio requirements for utilities in some parts of the world, this trend can be expected to accelerate.

Current State of Global Integration in the Wind Industry

Most debates surrounding globalization focus on the most visible mode, namely trade in goods and services. The same is true for the different initiatives to harness globalization for making green technology cheaper, better, and more widely available: They almost exclusively focus on cross-border trade flows

31. See American Wind Energy Association, Value Chain: Components of a Turbine, available at www.awea.org.

32. Data from BTM Consult (2009).

and related tariff and nontariff barriers.[33] However, the analysis of the global wind industry shows that trade has become relatively less important in the wind industry and firms have mainly used cross-border investment as a mode for global integration of their value chains.

An analysis of traditional cross-border world trade in wind turbines and related components is complicated due to various technical obstacles.[34] Table 6 presents the most recent (2008) data for global exports and imports in a trade category accounting for a large share of total trade in wind turbine components.[35] Unsurprisingly, the top global exporters of wind turbines are the home countries of the leading wind turbine manufacturers shown in figure 1, with Germany, Denmark, India, and Japan accounting for more than 90 percent of the 2008 global total. The United States was by far the largest importer of wind turbines in 2008, with developed economies Denmark, Spain, Japan, and Germany shipping 85 percent of total US imports.[36] The domestic focus of China's leading wind turbine producers found in figure 1 is verified by the modest scale of Chinese exports in 2008.

Even taking into account that table 6 shows only a large share but not all of total wind turbine-

33. See, for instance, International Chamber of Commerce (2009), ICTSD (2008), and Reuters, "GE Calls for Trade Deal in Environmental Goods," October 22, 2009, available at www.reuters.com.

34. Precisely tracking all trade flows in the wind industry is like tracking trade flows in any environmental good, complicated by the fact that the standard Harmonized Commodity Coding and Classification System (HS) does not have separate internationally harmonized 6-digit trade categories for wind turbines and their components. World trade data for wind turbines are therefore inherently imprecise. HS 8502.31 "Wind-powered electrical generating sets" includes fully assembled wind turbines but may also include components of wind turbines. This category would not include goods not destined for inclusion in wind turbines. However, individual turbine components may also be transacted under other HS headings (such as gearboxes in HS 8483.40 "Gears and gearing [excluding toothed wheels, chain sprockets, other transmission elements presented separately]; ball/roller screws; gearboxes, other speed changers, including torque converters"), where they will be classified together with other items not destined for use in the wind industry. Including "dual-use" categories such as HS8483.40 in wind industry trade would therefore lead to a potentially large overestimation of the levels of such trade. More detailed data for wind industry trade flows are available for individual countries at up to the 10-digit level, but estimating global flows at this level is not meaningful as individual country 10-digit classifications are not harmonized. So-called ex-outs, which separates wind industry goods from non-wind industry goods within individual HS categories, are also not harmonized across countries. See Lako (2008), Wind (2008), and Steenblik (2005).

35. Table 6 includes only HS 6-digit category 8502.31and not categories for individual components, due to the issues described in the previous footnote. The data in table 6 are therefore an underestimate of total trade in wind turbines and related components. A more detailed 10-digit data selection from USITC (2009) of wind-related HTS categories, including also four "dual-use" 10-digit HS categories (US HTS 8501.64.0020, 7308.20.0000, 8412.90.9080, and 8503.00.9545) in total US trade, suggests that HS 8502.31 includes approximately half of US imports of wind turbine related trade. The trend in the sum of the trade in the combined five HS categories tracks US installed capacity very closely, suggesting that inclusion of these four additional HS categories validly captures the level of US wind turbine related imports. Moreover, the principal countries of origin for the four additional "dual-use" 10-digit HS categories are the same as for HS 8502.31.

36. Table 6's export and import data are presented by reporting country, such that export data are reported by the exporting country and import data by the importing country. The standard statistical issues of "mirror data," where world exports and imports for a detailed commodity do not equal one another is clearly visible in table 6's 2008 data, which shows world exports totaling \$4.85 billion and world imports \$6.25 billion, or almost 30 percent higher. Timing and recording issues and inconsistent data collection techniques across countries typically account for the majority of mirroring inaccuracies, which in table 6 are not of a magnitude that affect the conclusions drawn here materially.

related trade in 2008, global trade magnitudes were relatively modest for an industry with $45 billion to $50 billion total sales in 2008 and $51.8 billion in investment in 2008[37] at around 10 percent. Given the bulk of many parts of wind turbines and the associated need for special transportation equipment and high costs described in tables 4 and 5, this relatively low level of trade is not surprising.[38]

Moreover, the level of trade intensity in the wind industry is declining. Global wind turbine exports[39] recorded in HS 8502.31 rose by more than 50 percent from $3.19 billion in 2006 to $4.85 billion in 2008, measured in current prices. Yet, during this period of more than 20 percent project cost increases in the wind industry,[40] global annual installed wind capacity nonetheless went up by more than 75 percent from about 15,000MW in 2006 to 27,000MW in 2008 (GWEC 2007, 2009b). A rough and ready estimate therefore suggests that global cross-border trade intensity in the wind industry might have fallen by as much as a third from 2006 to 2008.

The decline in cross-border trade intensity in the wind industry implies that the share of local content (produced by domestic and foreign-owned firms) increased. This is caused partly by new domestic-only turbine producers (especially in China), as well as rapidly rising levels of FDI by leading manufacturers in new, growing wind energy markets. The Chinese market supply has changed from being dominated by foreign turbine producers in 2005 to be supplied by local manufacturers at levels as high as 70 to 80 percent in 2008–09 (USITC 2009, figure 20; BTM Consult 2009; authors' interviews).

The rapid increase in wind industry FDI is illustrated in figure 2, which breaks down greenfield investments in wind turbine related production from 101 recorded projects by destination country.[41] Included are investments from nine of the top 15 companies included in figure 1, which created an estimated over 20,000 jobs over the period.[42] Wind turbine investment flows into or within the European

37. See GWEC news release at www.gwec.net; see UNEP SEFI (2009) for investment data.

38. Special trucks, railroad carriages, and cranes are required to transport very heavy or very large wind turbine nacelles, tower components, and blades. Estimates from the American Wind Energy Association (AWEA) suggest that per-turbine transportation and logistics costs range from $100,000 to $150,000. See "Slow, Costly and Often Dangerous Road to Wind Power," *New York Times*, July 22, 2009, www.nytimes.com.

39. Given the relatively small number of large firms that dominate the global wind industry, the statistical coverage of world wind turbine exports is likely somewhat better than for the more diverse importers. For this reason, reference is made here to export rather than (higher) import data. The trend in reported aggregate global import data, however, closely mirrors that of export data from 2006–08.

40. The DoE (2009) reports average installed projects costs in the United States rose from approximately $1,570/KW in 2006 to $1,925/KW in 2008 or more than 20 percent during the two-year period. BTM Consult (2008a) reports this to be a global trend.

41. The fDiIntelligence database includes only "greenfield investments" and not M&A transactions. Furthermore, only investments where a direct link to wind turbine production could be identified are included. This will mean that some investments in wind turbine supply industries are excluded. As such, the data in figure 2 are likely an underestimate of true investment flows in the wind industry. For comparative reasons with EU aggregates included, data in figure 2 include domestic investments across state and provincial lines.

42. This number includes both announced project job creation and estimates by fDiIntelligence for projects where no job creation numbers were available.

Union grew steadily to about $750 million from 2003 to 2008, while the really big increase to nearly $1 billion annually is found in investment flows into or within the United States in 2007 and 2008. China in comparison saw relatively few investments early in the period, but in 2008 and 2009 became the third largest destination. Meanwhile investment inflows to other destinations remained limited. India was not a major recipient of investment, reflecting the relative unattractiveness of the domestic market in the absence of broad and stable support policies. The impact of the global financial crisis is clearly evident with the collapse of investments in 2009.

The rapid growth of the US market has turned the United States into an important destination for FDI. All leading European, Japanese, and Indian wind turbine producers identified in figure 1 (except Germany's Enercon) operated production facilities in the United States or planned to begin operating by 2010.[43] China has experienced a similar, if smaller recent boom of foreign investment in wind energy equipment manufacturing. In all major markets there also is a trend known from the auto industry that major parts suppliers follow in the heels of turbine producer FDI and locate their own production facilities close by.[44] USITC (2009) identifies a large number of US-based suppliers to turbine manufacturers, which have recently entered the market place. Another organizational trend seen among several large turbine producers is a move towards increased vertical firm integration, with several leading turbine producers moving to take production of key components in-house in recent years.

Correspondingly, the local content of wind turbines installed in the United States has increased quite dramatically in recent years. Relying on detailed 10-digit HTS US import data from USITC (2009) (see footnote 33), annual US installed capacity data from the Global Wind Energy Council (GWEC)/ American Wind Energy Association *(*AWEA), and annual weighted installed capacity cost data from the DoE,[45] US local content has risen from an average of less than 20 percent from 2001–06 to just over 50 percent by 2008.[46] This rise in US local content will predominantly have come at the expense of the principal European exporting nations, especially Germany and Denmark.[47]

43. USITC (2009), BTM Consult (2009), AWEA (2009b), and a survey of company websites in October 2009.

44. At the same time, it should be emphasized that several of the major suppliers, such as SKF, ABB, and Bosch-Rexrodt, to turbine producers are major multinational companies in their own right, who have their own global production strategies independent of turbine producers.

45. These data were provided by Dr. Ryan Wiser and Mark Bolinger from the Lawrence Berkeley National Laboratory and are on file with the authors. Following table 4, 75 percent of installed annual project costs are attributed to potentially tradable capital equipment.

46. This estimate corresponds roughly to the AWEA estimate of an increase in US local content from under 30 percent in 2005 to about 50 percent in 2008 presented in the 2008 AWEA Market Update, available at www.awea.org. Due to the large fluctuations in annual US installed capacity in the 2000–05 period illustrated in figure 1, we consider it appropriate to use a multi-year average as baseline.

47. The much-reported closure of Vestas' Isle of Wright blade production facility in August 2009, for instance, was directly related to the decline in US-bound exports from this facility. See "Vestas UK chief says Britain must speed up wind farm construction," *Guardian*, August 7, 2009, available at www.guardian.co.uk.

Exporters from low-cost manufacturing countries are not a serious competition for newly emerging domestic suppliers in the United States thus far. Early attempts of sourcing turbines for the US market from China such as the GreenHunter-MingYang cooperation were cancelled in light of improved domestic supply capacity.[48] The recently announced wind park in Texas by US-based private equity firm US Renewable Energy Group (US-REG) and China-based Shenyang Power Group highlights two interesting developments: First, wind power needs large amount of capital, and capital inflows from China might—given the vast amount of foreign exchange reserves and its increasing financial power—begin to play an increasingly important role in financing the low-carbon future of the United States.[49] Second, public investors might sometimes make choices of turbines that are not purely related to price and quality competitiveness or other commercial calculations but to industrial policy objectives or political quid-pro-quo expectations (box 2). Yet, this investment is also part of a broader non-wind industry financial diversification trend in capital inflows from China, and as long as such projects do not become the dominant form of wind power investment, they should not be misread as an indicator of a switch away from the predominantly local supply chain organization for the entire industry.

The finding that relatively large national markets for wind turbines tend to see either the emergence of dominant domestic wind turbine producers (as in earlier years in Denmark, Germany, Spain, United States, India, and now China) or the inflow of wind turbine producer FDI[50] is consistent with several strands of the theoretical FDI literature. The "proximity-concentration hypothesis" from Brainard (1993) and Markusen and Venables (2000) suggest that FDI is positively correlated with high transportation costs, as found in the wind industry. Similarly, as posited by Helpman, Melitz, and Yeaple (2004), in a world of heterogeneous firms, FDI will increasingly dominate export sales in sectors where fixed establishment costs decline and variable trading costs remain high.

Future of Globalized Wind Industry Value Chains

We just illustrated the gradual consolidation of the wind industry into regional production hubs with increased levels of local content in the United States and increasingly China and continued self-sufficiency in but declining exports from the European Union with corresponding declining global trade intensity in the industry. Current debates in the United States and other developed economies voice the concern that these patterns could be reversed and that large parts of the value chain could migrate

48. GreenHunter Energy Inc., "GreenHunter Energy Announces Sale of Equity Ownership Interest in Chinese Wind Turbine Manufacturer for $9.1 Million," October 28, 2009, press release available at www.reuters.com.

49. See box 2 and the recent interest of China Investment Corporation (CIC), China's sovereign wealth fund, in acquiring a stake in the wind development business of Virginia-based power company AES, available at www.china-inv.cn.

50. This is occurring especially in the United States but was also seen earlier in smaller individual European markets in Spain, Portugal, the United Kingdom, or Italy as well as in India in the early 1990s. See BTM Consult (2008a) and Lewis and Wiser (2007).

Box 2 A Texas wind farm, Chinese turbines, and a New York senator

On October 29, 2009, the first major US wind park to be supplied with Chinese-manufactured wind turbines was announced as a joint venture between a US private equity firm, US Renewable Energy Group (US-REG), and a Chinese renewable energy company, Shenyang Power Group (SPG),[1] which is partly owned (20 percent share) by the local Shenyang government (A-Power Energy Generation Systems Ltd. 2009a, 12). The Chinese wind turbine producer A-Power Energy Generation Systems in Shenyang is supplying 240 2.5MW turbines to west Texas between March 2010 and March 2011. The $1.5 billion project costs will be financed by Chinese state-owned banks via the intermediation of SPG (A-Power Energy Generation Systems Ltd. 2009b, 5). The project is the first time Chinese-manufactured wind turbines are to be imported to the United States, while up until recently the majority of wind turbines installed in the United States were imported from Europe. At first sight this project seems to run counter to the wind industry trends described in this paper.

However, the project costs of $1.5 billion, or $2,500/KW, is actually significantly above the Department of Energy (DoE 2009, figure 22) estimates of Texas' average for capacity weighted installed project costs of roughly $1,800/KW for 2007–08 and even above the highest individual project cost in the sample (of 20 projects accounting for 2,799MW) of about $2,200/KW. As such, using Chinese-manufactured wind turbines seems significantly more expensive than the average for Texas wind projects, where in 2009 prices can be expected to have even come down somewhat since 2007–08 following the US wind energy slowdown in 2009. Hence, it seems reasonable to assume that this is an outlier and not a project based solely on commercial considerations and that the Shenyang government possibly has insisted on the turbines being produced in Shenyang as a quid-pro-quo for its involvement.

There are also more noteworthy aspects of this project. The Chinese manufacturer A-Power licensed on commercial terms the 2.5MW wind turbine technology involved from the German turbine producer Fuhrländer for a transfer fee of approximately $6.4 million and a minimum of approximately $8.1 million in training fees and a royalty payment over the first six years of the agreement (A-Power Energy Generation Systems Ltd. 2009c). As such, the project indicates both the large recent progress made by the Chinese wind turbine industry and its current limitations.

Additional Chinese-financed investments in Chinese-made wind turbines into the US market similar to the Texas project cannot be ruled out in the immediate future. However, the abnormal particulars of the Texas projects does not suggest that in the long term Chinese wind turbine producers will globalize their operations in foreign markets in a manner different than earlier European wind turbine producers. As such, the most likely long-term market supply strategy for Chinese wind turbine producers for the US market remains future foreign direct investment (FDI). Indeed, a subsequent announcement by A-Power and US-REG (A-Power Energy Generation Systems Ltd. 2009d) attests to this view, as the joint venture announced their intention to develop a manufacturing and assembly facility in the United States to assemble wind turbine generator set components.

In addition, though, the Texas project created a political outcry in the United States. On November 5, New York Senator Charles Schumer wrote to US Energy Secretary Steven Chu to request that the project be denied financial support from the Obama administration's 2009 American Recovery and Reconstruction Act (ARRA) funds[2] on the grounds that jobs were created from stimulus funds in China rather than the United States. This highlights a lasting tension between the long-term policy aims for promoting US renewable energy and the short-term imperatives of stimulating US job creation.[3]

(box continues next page)

1. See US-REG press release at www.us-reg.com/news.

2. See Charles Schumer press release, November 5, 2009 at http://schumer.senate.gov.

3. Schumer's announcement further ignores the issue that the only "long-term"—i.e., lasting for the operational life of the wind turbines—jobs created from any single wind project is in operation and maintenance (O&M) services. All these jobs in the Texas project will be located in the United States, while only the "temporary" manufacturing jobs from the one-off production of the 240 wind turbines will be in China. Lasting manufacturing jobs in the wind turbine industry are generated only through sustained expansion of installed wind turbine capacity through many individual wind farm projects.

Box 2 A Texas wind farm, Chinese turbines, and a New York senator *(continued)*

The issue that Schumer raised is that the project—as any current US wind farm project—will benefit from US financial support provisions for wind (and other renewable energy sources) included in the ARRA stimulus package. The ARRA stimulus bill included among its provisions renewed funding for the 2009–12 period for the existing production tax credit (PTC), as well as other incentives for US wind power.[4] Hereby, pre-existing policy support measures for wind energy suddenly became funded through a "legislative vehicle" in the US Congress that saddles them with even more explicit requirements for quid-pro-quo local job creation than usual. This shows the danger of trying to achieve two policy objectives—increased investments in wind power and immediate local job creation—with the same policy tool, the PTC.[5]

Such calls for "Buy American" in a stimulus package aimed at generating US jobs, but which also funds support measures for wind (and other renewable energy sources), exemplifies how explicit political quid-pro-quo expectations for local job creation are always on the agenda in any industry that—like wind power—benefits from direct taxpayer financed support.

4. See the AWEA website at www.awea.org for a detailed description of wind stimulus measures included in the ARRA.

5. See also Jacob Kirkegaard, "Senator Schumer's Blowhard Moment?" RealTime Economic Issues, Peterson Institute for International Economics, November 18, 2009, www.piie.com.

to low-wage destinations, especially China and India. However, given the cost composition of major turbine components, such a scenario seems unlikely. The most likely future for the industry is continued market-seeking, FDI-driven global integration, and possibly the emergence of new domestic producers in sufficiently large markets. Trade flows will likely remain a complement, allowing firms to flexibly source certain low-trading cost parts.

Raw material costs are by far the most important component in all principal wind turbine components, ranging between 60 to 90 percent of total costs (table 7). With raw materials accounting for the lion's share of total turbine costs, rapid turbine cost inflation during the recent run-up in world commodity prices was unavoidable. Labor on the other hand accounts for a rather modest share of total turbine costs: Aside from the final assembly process of the full nacelle (i.e., of gearbox, generators, bearings, and other main components inside the nacelle), which is relatively labor intensive, only blade production entails significant labor costs. Intellectual property included in table 7 in the residual "other costs" category accounts for perhaps 2 percent of total turbine costs, with intellectual property in gearboxes, bearings, and blades accounting for the bulk hereof.[51]

This combination of low labor input, high transportation costs and uniform world commodity prices makes it difficult for turbine producers to achieve large cost reductions by shifting turbine

51. This estimate is based on our interviews with industry experts and an analysis of various technology licensing agreements.

production to low-cost locations. Barring unexpected radical new innovations in wind turbine design or other factors distorting the global cost picture,[52] industry investment location decisions can therefore be expected to remain predominantly market-seeking (i.e., investments in turbine production facilities go to the countries where demand for turbines exist) and regionally dispersed. The reemergence of globally dominant centers of wind turbine production similar to Europe during the 1990s is unlikely.

Regarding the potential for increasing global integration of wind industry value chains, industry experts expressed the belief that some turbine components (noticeably relatively easier to transport bearings and gearboxes) will be more mobile and subject to industry consolidation and economies of scale in the future. As such, increased global sourcing of such less bulky components could be envisioned from Northeast Asia (China, Korea, and Japan), where forgings and cast iron supply facilities are abundant. Similarly, several industry experts conveyed that some countries would be able to continue to benefit from existing strong competitive positions in wind sector related services, such as R&D services in Denmark and Germany and perhaps financial services in the United States. Within regional production hubs, countries with relatively low labor costs might have an advantage in the final assembly of the nacelle if they possess the necessary infrastructure and skilled labor. This seems to suggest a win-win situation with opportunities for different countries to develop comparative advantage in different activities along the wind value chain.

EXISTING BARRIERS TO GLOBAL INTEGRATION IN THE WIND SECTOR

Both cross-border trade and FDI have driven the global integration of the wind industry, with FDI becoming increasingly important over time compared with other industries. In addition to commercial calculations, government policies are shaping the choice of firms between trade and FDI as globalization vehicles. This section analyzes the degree to which national investment, trade, and industrial policies impede market-based developments in the global wind sector and prevent firms from streamlining their value chains in the most efficient way across borders in their efforts to reduce costs.

Tariffs

One potential barrier is tariffs, which increase the cost of trading and put an incentive on firms to relocate production to a less efficient location to avoid these costs ("tariff-hopping"). Completely eliminating global tariff barriers would be beneficial to trade growth in the wind industry and likely increase dispersion of wind turbines especially to some developing countries, if these countries simultaneously implement the kind of financial support measures discussed earlier. Yet, it is unlikely that such international policy action would independently lead to any noteworthy acceleration of global

52. For example, national industry policies that substantially influence the cost of input materials.

wind industry activity or significantly increase the level of global installed capacity.[53] Data from the World Trade Organization (WTO) in table 8 clearly show that while bound tariffs remain high in many WTO members, presently average actually applied tariff barriers in the wind industry (HS 8502.31) are at relatively modest levels, with most developing countries applying tariffs of only 10 percent or less (Steenblik and Matsouka 2008). The US and EU tariffs are at 1.3 and 2.7 percent, respectively, China at 8 percent, while India has dramatically reduced its applied HS 8502.31 tariffs from 25 percent in 2002 to 7.5 percent in 2008, and applied tariffs in many developing countries are in fact zero.[54] A special recent case is Brazil, which in June 2009 increased tariffs on wind turbines up to 2.6MW from zero to 14 percent from 2010 onwards (GTA 2009). This decision coincided with a major expansion of the Brazilian government's Program of Incentives for Alternative Electricity Sources (PROINFA) for wind energy and replaces an earlier explicit 60 percent local content requirement for Brazilian wind turbines. The latter has been widely criticized for creating significant bottlenecks in the supply of wind turbines in Brazil, and the switch to a tariff-based trade barrier hence represents a change in the choice of protectionist policy tool by the Brazilian government.

Local Content Requirements

A second widely discussed variable that is intervening in firms' decision-making are local content requirements (LCRs). Similar to tariffs, LCRs might cause "trade barrier–hopping FDI flows" to participate in a market if local content is mandated.[55] This type of provisions mandates the use of locally manufactured components or technology in installed wind turbines. Foreign (and domestic) companies wishing to sell their products in a given market are consequently compelled to relocate their own production facilities to the market in question, enter into a joint venture with local producers, or source their components locally.

These rules are often implemented at the subnational government level, adding considerable uncertainty to the enforcement process (which might vary from province to province) and forcing producers to locate in very specific parts of a particular market. Lewis and Wiser (2007) describes how

53. Estimates in World Bank (2007) of a 12.6 percent increase in world trade from elimination of tariffs in wind power generation, based upon a larger group of commodities, thus seem optimistic.

54. While individual wind turbine components can also be imported separately and under different customs headings than HS 8502.31, and some countries have encouraged this practice to spur local assembly by lowering tariffs in other applicable categories to below the levels in HS 8502.31, it is reasonable to regard tariff levels in HS 8502.31 as the tariff ceiling for wind turbine components. This is so, as described in Wind (2008), due to the provisions that qualify individual wind turbine components to be included in 8502.31 when these are presented for customs purposes together "as a set." If tariff levels therefore are relatively lower in 8502.31 than in individual component categories, producers will almost always have the option of qualifying for customs processing in 8502.31 for any included component.

55. World Bank (2007:62) identifies nontariff barriers from several developing countries as far more important than tariff barriers. The order of the examples below must not be taken as an implied ranking by severity, as available data do not allow such analysis.

such provisions have been used extensively in Spain, Brazil, Canada, and China (Steenblik and Matsuoka 2008). As described above, the wind industry tends to be organized around regional hubs, because of the particularities of the industry, such as high transportation costs. LCRs can reinforce this if the market is large enough, for example, in China. The combination of a large market and a 70 percent LCR has led the majority of the 12 non-Chinese turbine producers listed in figure 1 to establish production facilities in China.

However, explicit and detailed LCRs significantly reduce investing firms' operational flexibility and efficiency in production, which increases costs. By giving firms detailed requirements for which parts have to be sourced locally, firms face supply bottlenecks if domestic suppliers in new markets cannot deliver to the necessary extent and the required quality or time period. Exactly this happened in China after the imposition of the LCRs (BTM Consult 2009). China's decision in October 2009 to remove its explicit LCRs for wind turbines[56] will likely not make much difference for supply chain decisions, as China has already built up substantial domestic wind turbine production capacity, following the industry dynamics and cost structures favoring local supply described above. However, it will increase firms' flexibility in organizing their supply chains.[57]

Differing Industrial Standards and Certification Requirements

A third and less discussed barrier to global streamlining of value chains, no matter via FDI or trade, are different industrial standards and certification requirements. In capital-intensive industries like wind energy, where large upfront capital investments must be made and financed, the standard product life is 20 years, and the product made (electricity) is an integral part of any nation's key public infrastructure, standards and certification requirements are often crucial in conveying the required confidence and trust between manufacturers, operators, owners, financial institutions, and national authorities. Unless wind turbines used in particular wind park projects have specified industrial certifications, it will often be impossible for developers to secure project financing. In short, adhering to standards is what makes a project sufficiently trustworthy to be "bankable."[58] Correspondingly, the wind industry operates under a series of internationally recognized standards issued by the International Electrotechnical Commission (IEC)[59] or the International Organization for Standardization (ISO),[60] while most leading wind turbine

56. See Office of the US Trade Representative, US-China Join Commission on Commerce and Trade, Fact Sheet, October 2009, available at www.ustr.gov.

57. Authors' interview with industry expert, fall 2009.

58. Strict product quality standards are often theoretically assumed to favor company internalization of production and sales through FDI, rather than exports and arm's length transactions. The wind industry verifies this hypothesis.

59. See the IEC website at www.iec.ch. According to the AWEA, 11 IEC standards are currently in place for the wind turbine industry. See www.awea.org.

60. See ISO wind turbine standards at www.iso.org.

producers also acquire private product/project certifications issued by organizations like Det Norske Veritas (DNV).[61] At the same time, additional compulsory national standards of varying stringency for many wind turbine components have been employed by a number of countries, such as Denmark, Germany, Japan, India, and United States, and are likely to be introduced in China in the future.[62]

An illustrative example of the impact of different national standards on wind turbine design is given in Vestas (2009), where there is a 30-ton difference in the weight of the tower for the V-90 3MW turbine between the international "IEC IIA standard" and the German-only "DIBt II" standard.[63] Such differences in national standards can undermine economies of scale and add greatly to the costs for producers of entering new markets. This is despite the fact that the WTO Technical Barriers to Trade Agreement, of which most major wind turbine market countries are members, requires that technical regulations "are not prepared, adopted or applied with a view to, or with the effect of, creating unnecessary obstacles to trade" (Article 2.2).[64] The issue of certification requirements is also especially important for the services sector that is emerging around cross-border wind energy value chains. Globally operating firms that provide services like wind site assessments, financial due diligence or project development services often face very high entry barriers in the form of approval processes and requirements to cooperate with local firms and government agencies.[65]

Political Quid-Pro-Quo Expectations

Finally, there are political quid-pro-quo expectations; it was illustrated above how direct government financial support has continuously been the critical basis for wind industry growth. As such, by channeling large sums of taxpayer money (or other fee revenue paid by all power consumers) towards a favored industry, straightforward expectations of politically useful "returns" in the form of local investments and job creation are formed. For "political expectations" to be formed, it is irrelevant

61. See DNV wind energy certifications at www.dnv.com.

62. See Lewis and Wiser (2007). China in 2008 notified the WTO Committee on Technical Barriers to Trade (TBT) that they intended to implement a compulsory certification system for products relating to safeguarding national security, preventing deceptive practices, protecting human life or safety, animal or plant life or health, and the environment. This CCC (China Compulsory Certification) system would include wind energy related products. See WTO Documents G/TBT/N/CHN/399 and G/TBT/M/46 and draft regulation at http://members.wto.org. See also EU Chamber of Commerce (2009).

63. Deutsches Institut für Bautechnik, www.dibt.de.

64. The WTO TBT Preamble on the other hand provides significant freedom for members to implement standards by stating that "no country should be prevented from taking measures necessary to ensure the quality of its exports, or for the protection of human, animal, and plant life or health, of the environment, or for the prevention of deceptive practices, at the levels it considers appropriate." See www.wto.org.

65. Industry experts referred to complicated and time-consuming approval procedures in several European countries. A special case is China, where government-owned planning and design institutes are involved in the licensing process for foreign service providers but at the same time compete with them for business.

whether the wind industry benefits directly from taxpayer funds or through nominally nontax measures such as mandatory surcharge fees or purchase requirements for wind-produced power passed on to all electricity consumers. The key issue is that elected politicians mobilize the "state's coercive power" to channel societal resources towards a favored industry and for this, they expect something in return.

Hence wind industry investments share at least some characteristics with general "government procurement," an area of international trade that is only very gradually being liberalized and opened up to international competition.[66] Hard-to-quantify political quid-pro-quo expectations will work hand in hand with explicit LCRs to guarantee that local investments and job creation are secured. Or they might operate independently, as in the world's largest wind industry FDI destination market in the United States, which has no explicit LCRs[67] but where the political process makes it extremely politically advantageous to produce wind turbines locally.[68]

Concerns over favoritism for local producers have been raised in both the United States and China. In the United States, the debate has centered on "Buy American" provisions in the stimulus package. When financial incentives for wind energy are appropriated through emergency stimulus programs, political quid-pro-quo expectations are even higher than usual, because the long-term policy aim of promoting wind energy is directly mixed up with the short-term policy goals of immediate domestic job creation and economic growth.[69] In China, the main source of concern has been the exclusion of foreign wind turbine producers from recent large government project auctions.[70] This type of de facto direct discrimination against foreign-owned firms with operations in China evidently goes beyond both LCRs and political quid-pro-quo expectations and instead makes up a quite openly nationalistic industrial policy.[71] Reducing the importance of direct government financial support measures, perhaps by relying

66. Only a minority of 40 principally developed country members of the WTO are parties to the Government Procurement Agreement (GPA) aimed at enhancing transparency, market access, and nondiscrimination in government procurement decisions. In 2004 government procurement was explicitly removed from the agenda of the Doha Round negotiations. See the WTO GPA at www.wto.org.

67. Recent "green stimulus spending" has local content requirements (Buy American provisions) at the state and local level. See Hufbauer and Schott (2009).

68. An indication of the existence of "nonmarket influences" in US wind power is New York Attorney General Anthony Cuomo's ethics "Code of Conduct for Wind Farm Development," adopted by wind industry companies in July 2009. The code aims to "deter improper relationships between wind development companies and local government officials." See New York Attorney General's Office press release, July 29, 2009, available at www.oag.state.ny.us.

69. Note that a similar risk also exists in other countries The Organization for Economic Cooperation and Development (OECD 2009) describes how all OECD countries have explicitly "green investments" in their recent policy responses to the economic crisis.

70. No foreign turbine producer has been awarded any projects in the Inner Mongolia/Hebei and Gansu Wind Bases totaling up to 15GW of capacity (Soares 2009).

71. According to a Xinhua News Agency report (2009), the irony is that explicit favoritism of Chinese producers will clearly have added to local interest in entering the wind turbine market and subsequent concerns about overcapacity. This suggests that in the wind industry there is a clear disconnect in policy between the central government in Beijing, which

increasingly on indirect support in the form of a price on carbon emissions, will be a first step towards abating political quid-pro-quo expectations in the wind industry.

Summing Up

The impact these barriers have on firms' decisions is complex. They will interfere with firms' supply chain allocation decisions and thus put upward pressure on wind turbine prices in a given market. However, at least two of the three nontariff barriers—LCRs and political quid-pro-quo expectations—will likely work to promote inward FDI at the expense of cross-border trade, while divergent industry standards and certification requirements cause a general increase in costs, irrespective of the mode of international transaction. At the same time, the size of the domestic market matters. If the market is big enough and the industry has high trading costs as in wind energy, basic market dynamics in an open global economy would likely lead to eventual establishment of a local production capacity, even in the absence of LCRs or political quid-pro-quo expectations. As such, in large markets such as China, their effect is likely mostly to accelerate and cement an inward investment trend, rather than independently trigger new investments.

GLOBAL INTEGRATION AND LOCAL JOB CREATION

As the wind industry benefits from significant direct and indirect government financial support, it is unavoidable that expectations of job creation play an often decisive role in investment and regulatory decision-making.[72] In this light, investment and trade policies that foster global integration may be interpreted as the equivalent of shipping green jobs overseas. However, our review of existing literature suggests that wind power creates more jobs than power generation from traditional fossil fuels, while our analysis of wind industry value chains shows that globalization will have only a relatively small impact on local job creation compared with other industries during the process of global integration.

Comparative studies on the job impact of various energy sources have shown that wind power on average generates more jobs than do fossil fuel–based power sources during manufacturing, construction, and installation, reflecting both the complexity of wind turbine sourcing and production described in table 5 and the relatively dispersed nature of wind power (many turbines versus a single power plant). At the same time, wind power generates fewer jobs during O&M/fuel processing phases than do other sources of energy. This should not be surprising though, as first of all wind power requires no fuel processing (and as a consequence faces no supply security concerns), and second the wind industry as discussed above is

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attempts to restrain new entries into the wind sector, and Chinese provincial governments, which steers project orders directly and exclusively to Chinese producers.

72. Similar to almost any potential multinational investor, wind turbine producers in the United States and elsewhere generally also benefit from various direct investment subsidies enacted by local governments to attract investment. See Mattera (2009, 13).

characterized by rapid productivity improvements. Table 9 breaks down the job-generating potential of five different energy sources from a number of different studies into two categories (roughly replicating the two wind sector value chains described in table 5): jobs created during the "manufacturing, construction, and installation" phase and jobs created during the "O&M and fuel processing phase."[73] These estimates indicate that on average, wind is likely more employment intensive than fossil fuel–based power generation but generates less employment than, for instance, solar PV power production.

There are no reliable or accurate estimates for global employment levels in the wind energy sector. Table 10 gives an overview of existing estimates of national employment and employment distribution. According to EWEA, about two-thirds of the estimated 155,000 European wind industry jobs are with wind turbine and component producers, with the rest made up by wind farm developers, installation and O&M workers, independent power producer and utility wind workers, wind/site consultants, and financial advisors. The relatively large share of turbine/component producer jobs in Europe reflects the continent's status as the principal global exporter of wind turbines, as well as being the home base of most multinational wind companies. For the United States, AWEA (2009c) quotes 85,000 US jobs in the sector in 2008 (up from 50,000 in 2007). The AWEA employment breakdown shows US manufacturing jobs making up about a quarter of US total employment, with "other employment" comprising wind park developers, financial and consulting services, contracting and engineering services, part-related services, and transportation and logistics accounting for the bulk of US employment. This is noteworthy as it suggests that the United States has a comparably low share of manufacturing jobs compared with the other big regional markets.

A key question for policymakers is to what degree future additional global integration of the wind industry will affect local job creation in the sector. For them, the risks in committing taxpayers' money in support for the sector are evident, if ultimately many "green wind jobs" end up being offshored. Our analysis provides two key reasons for why these risks are lower than in other industries.

First, wind jobs will overwhelmingly follow wind power demand, as the wind industry is characterized by FDI-driven global integration and the emergence of new domestic producers in markets of sufficient size. This will ensure that global employment growth result in localized job creation in at least the big three regional production centers in the European Union, United States, and China. It will also mean that Europe will continue to lose some of its existing "export dependent jobs" to predominantly US and Chinese locations, while on the other hand the continent seems likely to benefit from most future job generation in the offshore wind sector.

Second, the characteristics of both supply chains described in table 5 make wind power relatively

73. See also Kammen (2007), Kammen and Engel (2009), and UNEP et al. (2008). Note that the data presented in table 9 are from Wei, Patadia, and Kammen (2009), a meta-study, for which the authors gathered estimates from several previously published studies. The data might therefore not accurately reflect the current industry employment generation capacity, due to technology improvements.

immune to jobs offshoring also in the long term compared with both fossil fuel and other renewable energy sources (especially solar PV). While the first (turbine production) chain is characterized by the bulky and hard-to-transport nature of many manufactured components, the second (wind power production) chain is predominantly made up of logistics, construction, and other wind services tasks bound to the local area.[74]

Precise forecasts of employment creation should be treated with care. First, many of the most optimistic forecasts rely on methodologies that include, in addition to direct and indirect (from input-output table analysis of supply chains) job creation, so-called induced job creation —that is, jobs resulting from the spending by people directly and indirectly supported by a green project, such as grocery store clerks, retail sales people, or child care providers (DoE 2008, appendix C). These effects are real, especially in many rural areas with few other sources of economic activity, but calculating the real and additional independent net job creation arising in this way is fraught with uncertainty. Second, the same learning curves that are making wind power ever more efficient and cost-competitive are making it less labor intensive. As with almost all manufacturing processes, we expect a shift in wind turbine production towards more capital-intensive processes, particularly in regions with high labor costs such as the European Union and United States. Similarly, as turbine designs improve and become more reliable, O&M should become both easier and less labor intensive.

Nevertheless, all sources and future projections that we have reviewed agree that the wind sector is destined for considerable job growth in the coming decades as global installed wind capacity continues to expand briskly. Wind energy has several appealing characteristics for policymakers seeking to build support for renewable energy by making a case for job creation. First, particularly during a period of growth, wind energy is likely to remain more labor intensive than traditional energy technologies. Second, the range of jobs created is attractive, including both blue collar manufacturing and a wide array of skilled scientific, engineering, and service roles. Finally, experience to date powerfully suggests that the bulk of jobs created will be where the market is—in other words, effective long-term measures taken to promote wind energy deployment will largely create employment in the same country or region.

CONCLUDING REMARKS

The wind power sector is among the most important commercial industries for climate change mitigation and is rapidly growing. Much of this growth is driven by government support aimed at not only reducing emissions and energy imports but also nurturing a new industry that promises substantial localized job creation. In this paper we have taken a closer look at the value chains underlying this industry to better understand some of the drivers and barriers to realizing this potential.

74. Wind service tasks are both varied and typically require high skill levels. Examples include meteorologists, wind surveyors, and structural, mechanical, and electrical engineers. See UNEP et al. (2008, 39).

The very rapid growth of the wind industry in recent years has been closely tied to direct government policy, taking the form of financial support measures and increased mandating of renewable power production or consumption requirement for utilities. The recent spike in commodity prices and associated cost increases in the wind power sector had only a negligible effect on industry global growth rates. The effects of the current financial crisis and global recession on future growth rates are also quite minor. Credible long-term government policy commitments to the wind power sector continue to trump cyclical swings in the broader economy.

The wind industry provides a clear example of how a “green Keynesian industrial policy” can work. If government policy creates sufficient demand for wind energy, local supply of wind turbines and related services will emerge either from new local entrants or via FDI. The wind industry is led by those countries that have developed large policy-supported wind energy markets. In part this has in some countries been aided by explicit LCRs, which have meant that building capacity in these markets was required. But it is largely due to the nature of wind technology itself. Wind turbines and their most important components are large, bulky, and difficult to transport, making trading them relatively expensive. This has meant that FDI rather than traded goods have played the most important role in internationalizing the industry. Perhaps reflecting this, traditional tariffs are quite modest in the wind industry today. However, nontariff barriers remain widespread, including LCRs, national industrial standards and licensing demands, and in particular politicized investment decisions biased in favor of local producers.

Accordingly, leading companies in this industry are based in those countries and regions that have established clear long-term policy drivers. Given EU leadership in applying this policy, European companies have historically been dominant. But there has been a relative shift to US and Chinese companies as the domestic markets in both countries have grown rapidly in recent years, as well as to India. The wind industry boasts prominent and successful developing-country participation with four of the top 15 globally leading turbine producers in 2008 being from emerging economies.

Commodity costs and localized investments dominate the wind industry’s value chains. Conversely, labor cost differentials and intellectual property are less important drivers of cost (see box 3). Intellectual property in particular is broadly and commercially available and as such is not a significant barrier to wind energy development. Job creation is significant and likely to remain concentrated in countries with significant domestic markets, though the labor intensity of the industry will decline as production becomes more efficient.

Our findings yield several policy implications:

1. The wind industry is a successful globally integrating industry with considerable developing-country participation. As such, it underlines the important gains possible for both developed and developing countries from a long-term vision of a global approach to a new energy economy.

Box 3 Intellectual property rights: A barrier to wind technology transfer and global integration?

A pertinent question in the current COP15 climate change negotiations concerns the role of intellectual property rights (IPRs) in wind energy and other renewable energy sectors. Do IPRs hinder the access of developing countries to wind power technology or act as a barrier to globalizing value chains—i.e., hindering developing-country turbine manufacturers or component suppliers from entering the local or global markets? This working paper contains several relevant findings for the wind industry: The low share of intellectual property costs in wind turbines shows how the wind industry is very different than, for instance, the pharmaceutical industry in its reliance on IPR-driven revenues (Abbott 2009). In the relatively technologically mature wind industry, where the basic know-how is cheap and readily available from turbine producers, intellectual property cost clearly has relatively limited impact on the final price of a wind turbine or wind park projects. This is illustrated in box 2, which describes the IPRs involved in Chinese turbines. Here the Chinese turbine manufacturer A-Power purchased the IPRs for its 2.5MW turbine from the German company Fuhrländer for a total of less than $15 million, including the training of its Chinese employees in Germany.[1] Meanwhile, the total project value of just the one 240-turbine wind farm in Texas is $1.5 billion, so that just less than 1 percent of the cost of that project was made up of IPR-related cost.

Studies and recent wind turbine producer annual reports indicate that patenting in the wind industry has picked up in recent years.[2] At the same time, however, analysis in Pew (2009) indicates that wind remains "patent light" with relatively fewer patents when compared with other renewable energy sources.[3] This is quite surprising, as wind, when compared with other renewable energy sources, is a far more commercially deployed technology. Commercial interest would predict that turbine producers would move aggressively to protect the proprietary value of offered products also through the use of patents. However, the actual number of patents is by itself a poor indicator of the importance of IPRs in a given industry. A single patent for a crucial technology can be a far larger source of revenue for the holder (or potential block on technology diffusion) than dozens of patents for more peripheral technologies. Moreover, in the wind industry, despite some instances of patent-related lawsuits,[4] by and large the fundamental know-how necessary to produce wind turbines is not protected by wholly privately owned IPRs.

The limited role of intellectual property in wind is also clearly illustrated by the prominent positioning of wind producers from developing countries noted in figure 1, several of which, like A-Power in China, started out by licensing technologies from European firms and subsequently quickly mastering and redeveloping these (see also Lewis 2007). Technology blueprints and licenses for wind turbines are readily accessible on cheap commercial terms from independent engineering and design companies providing such services.[5] Correspondingly, IPRs make up no noteworthy bottleneck for technology diffusion of wind turbine technology throughout the world and while some of the concerns expressed in the UNFCCC negotiating text in this regard might be relevant for other technologies they seem unwarranted with respect to the wind industry.[6]

(box continues next page)

1. See the Texas project press conference video, part 2, at www.us-reg.com/news.

2. See, for instance, Vestas (2008) and Lee, Iliev, and Preston (2009).

3. The other "clean technology sectors" included by Pew (2009) are batteries, fuel cells, hybrid systems, solar, energy infrastructure (grid), geothermal, and hydro.

4. GE Wind, for instance, has been involved in disputes regarding variable speed wind technology in the US market with both Germany's Enercon in the 1990s and Mitsubishi of Japan more recently. See *Wind Technology Trends: Why Small Steps Matter*, Renewable World Energy Magazine, September 2, 2009, available at www.renewableenergyworld.com.

5. See AMSC Windtec, Turbine Systems and License Portfolio: Most Important Facts for Decision Making, available at www.amsc-windtec.com. See also A-Power Energy Generation Systems Ltd. (2009c).

6. The May UNFCCC negotiation text, available at http://unfccc.int, mentions several options in paragraph 188: compulsory licensing; pooling and sharing publicly funded technologies and making the technologies available in the public domain

Box 3 Intellectual property rights: A barrier to wind technology transfer and global integration? *(continued)*

Instead, as explained in Maskus (2000), the historical evidence from other industries suggests that strong globally enforced IPRs in the wind industry would continue to be a key driver of the steep wind industry learning curve. With the fundamental wind know-how established, cheap, and widely available, wind industry learning curves will instead increasingly be driven by incremental technology improvements in, for instance, advanced rotor aero-design, light-weight materials, and control systems. With competition and the number of global market participants increasing, strong IPR protection will be required for companies to fund this type of R&D.7 It correspondingly seems to be in the interest of developing countries like India and China—already key participants in the global wind turbine market—to ensure that the IPR of their domestic turbine manufacturers is internationally respected and protected.

Current technology transfer barriers as they exist in the wind industry are less related to intellectual property ownership issues and more to recipient country capacity, cost of capital, and institutional deficiencies. Many of the existing barriers can be addressed by capacity building. Skilled people who understand the technologies are necessary to develop, install, maintain, and adapt wind power technologies to local circumstances. Capacity building is also crucial to enhancing enabling environments, by strengthening policymakers' ability to design and implement policies and measures that support and accelerate the diffusion process.

Wind technologies are readily available at reasonable commercial terms, when compared with the overall large project financing costs in the wind sector. Thus it seems evident that a focus from developing countries on accessing cheaper financing and lowering the domestic cost of capital would have a far larger impact on the diffusion of wind power in developing countries than the pursuit of compulsory intellectual property transfer.

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at an affordable price; and less developed countries should be exempt from patent protection of climate-related technologies for adaptation and mitigation, as required for capacity building and development needs. See also Lee, Iliev, and Preston (2009), Barton (2007), and University of California, Berkeley (2009).

7. For instance, Vestas (2008) in their latest annual report choose to highlight their increased patenting of this type of incremental R&D work. See DoE (2008, chapter 2) for a detailed analysis of areas for potential wind technology improvements.

2. With wind industry development led by cross-border investment, rather than trade issues, policymakers can encourage economies of scale and efficiency gains through three investment policy actions:

    * Although provisions such as LCRs have been used to secure political backing for financial support measures for wind energy and drive local employment creation, our analysis suggests that such job creation would likely occur without these requirements, especially in countries with large domestic wind markets. Given the importance of international cooperation on clean energy policy, LCRs should be phased out as soon as possible.

    * Policymakers could focus on the establishment of global wind industry product standards and/or mutually agreed product certification requirements for relevant key wind turbine components.

* Global integration of the wind sector could be encouraged through the establishment of an international sectoral Green Power Government Procurement Protocol, initially among "like-minded" countries, requiring enhanced transparency, national treatment, and nondiscrimination among local and foreign wind turbine producers, when large wind project contracts are awarded.[75]

3. Government support and enabling environments have been and will be crucial to the development of the wind industry. Policies that create stable long-term demand for wind energy are a better approach to create local jobs and make green energy cheaper than policies that aim at protecting domestic firms. A global climate change agreement can further support the diffusion of wind power in developing countries by providing support, both in terms of capacity building and financial support, to enable developing countries to put in place policy measures in favor of renewable energy, develop grid systems that can integrate wind power and lower the high cost of capital. Such an integrated approach is more helpful than the bare transfer of intellectual property rights to the developing world.
4. Trade barriers do not constitute a major obstacle to wind power deployment, but conversely provide little protection for domestic industries. Therefore, their removal would have little substantive impact. Governments that support wind power and want to increase the effectiveness in terms of installed capacity per taxpayer dollar spent, should however remove tariffs unilaterally to capture the related minor cost reductions. Furthermore, unilateral tariff removal in wind energy could be a powerful political goodwill gesture in currently deadlocked WTO trade negotiations. Coordinated unilateral action among "like-minded" countries could be the first step towards a global agreement for comprehensive free trade in all "green technologies" modeled on the 1995 Information Technology Agreement.
5. A successful conclusion of a global climate change agreement in the context of the United Nations Framework Convention on Climate Change (UNFCCC) and an associated expansion of global carbon pricing mechanisms and other policy drivers are vital. This will level the carbon playing field between wind and fossil fuel–based energy and potentially render the current effective direct public financial support for the wind sector increasingly unnecessary. With sufficiently high carbon prices, continued policy support will instead be provided indirectly to the wind industry (and other renewable sources) in an equal manner across renewable and fossil fuel–based energy sources. The risk of political interference in wind industry investment decisions could hereby be abated.

75. The recent announcement of a US-China bilateral agreement, which will see China remove its LCRs on wind products, is a potential important first step. See "China and US move to defuse trade row," *Financial Times*, October 29, 2009.

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Table 1 Trends in global installed wind turbine capacity, by region and income groups, 2003–08 (megawatts)

	2003	2004	2005	2006	2007	2008
Total global installed capacity	39,431	47,620	59,091	74,052	93,823	120,791
Average annual growth rate (percent)	26.8	20.8	24.1	25.3	26.7	28.7
	Average global growth rate 1990–2008: 25.9 percent					
	Annual increase from previous year in installed capacity, by region[a]					
Africa/Middle East	n.a.	60	19	107	161	130
Asia	n.a.	1,391	2,205	3,669	5,128	8,581
China	n.a.	197	496	1,344	3,306	6,300
India	n.a.	875	1,430	1,840	1,575	1,800
Europe	n.a.	5,890	6,251	7,665	8,576	8,807
North America	n.a.	474	2,663	3,203	5,635	8,869
United States	n.a.	351	2,424	2,426	5,249	8,346
Latin America/Caribbean	n.a.	48	5	295	24	94
Australasia	n.a.	327	328	111	158	506
	Share of global installed capacity, by region[a] (percent)					
Africa/Middle East	0.5	0.5	0.5	0.5	0.6	0.6
Asia	8.6	10.0	11.8	14.4	16.8	20.2
China	1.4	1.6	2.1	3.5	6.3	10.1
India	5.4	6.3	7.5	8.5	8.4	8.0
Europe	72.9	72.8	69.2	65.6	60.9	54.6
North America	17.0	15.1	16.6	17.6	19.9	22.8
United States	16.2	14.1	15.5	15.6	17.9	20.8
Latin America/Caribbean	0.4	0.4	0.4	0.7	0.6	0.5
Australasia	0.6	1.2	1.5	1.4	1.2	1.4
	Share of annual installed capacity, by country income group[b] (percent)					
Up to lower middle income (<$4,000 GDP/capita PPP 2008)	n.a.	10.9	12.7	12.2	8.0	6.7
Upper middle income ($4,001–$12,000 GDP/capita PPP 2008)	n.a.	6.2	8.3	15.2	19.9	27.3
High income (>$12,000 GDP/capita PPP 2008)	n.a.	82.9	79.0	72.5	72.1	66.0
	Share of total installed capacity, by country income group[b] (percent)					
Up to lower middle income (<$4,000 GDP/capita PPP 2008)	5.4	6.4	7.6	8.5	8.4	8.0
Upper middle income ($4,001–$12,000 GDP/capita PPP 2008)	3.9	4.3	5.1	7.1	9.8	13.7
High income (>$12,000 GDP/capita PPP 2008)	90.7	89.4	87.4	84.3	81.8	78.3

n.a. = not available

a. Data take into account annual decommissionings and are subject to rounding effects in regional totals

b. Income levels in GDP terms chosen to approximate World Bank GNI-based classifications from 2008 rounded to nearest whole thousand. See http://siteresources.worldbank.org/datastatistics/Resources/class.xls.

Sources: IMF (2009); GWEC (2005, 2006, 2007, 2008); EWEA (2004); BTM Consult ApS (2009).

Table 2 Projected growth of installed capacity 2009–2013, including offshore (megawatts)

Country	2009	2010	2011	2012	2013
Asia	9,650	10,300	12,400	13,400	15,300
China	7,300	7,500	8,500	9,000	10,500
India	2,100	2,500	3,500	3,750	4,000
Europe	11,580	13,505	15,900	18,080	20,150
North America	7,000	9,700	11,500	15,000	17,000
United States	6,000	8,500	10,000	13,000	14,500
Other	2,395	3,135	4,020	4,910	6,070
Total	30,625	36,640	43,820	51,390	58,520
Total global installed capacity	152,783	189,423	233,243	284,663	343,153
Average annual growth rate (percent)	25	24	23	22	21

Sources: BTM Consult ApS (2009).

Table 3 Annual installed capacity in the United States, Denmark, Germany, and Spain, 1996–2008 (megawatts)

	Countries with expiring financial support measures		Countries in which financial support measures do not expire	
Year	United States	Denmark	Germany	Spain
1996	1	214	428	n.a.
1997	8	309	534	n.a.
1998	142	316	793	419
1999	659	316	1,568	746
2000	67[a]	636	1,665	613
2001	1,694	106	2,659	1,191
2002	412[a]	393	3,247	1,490
2003	1,672	225	2,645	1,327
2004	372[a]	8[b]	2,037	2,299
2005	2,420	4	1,808	1,523
2006	2,454	8	2,233	1,595
2007	5,249	–12	1,667	3,508
2008	8,545	24	1,665	1,609

n.a. = not available

a. Year with no US renewable energy production tax credit (PTC) in force.
b. Year in which maximum Danish feed-in tariff for new grid-connected wind turbines expire.

Note: Danish installed capacity fell in 2007, due to scrappings of older wind turbines surpassing new installed capacity.

Source: AEE (2009); DoE (2009); wind-energie.de; Danish Ministry of Energy (2009).

Table 4 Lifecycle breakdown of a wind energy investment project (percent)

Wind power project costs	Percent of total capital costs	Percent of total life-time project costs
Fixed upfront capital costs		
Capital equipment costs	75	58
Turbines (excluding blades and towers)	45	35
Blades	10	8
Towers	12	9
Equipment transportation	8	6
Other materials; land purchase, concrete, transformers, high-voltage extensions/electrical equipment, cables and road/site preparation	16	12
Construction labor subtotal	7	5
Other costs; wind mapping/site consulting, legal services/ certification and financing	3	2
Total fixed upfront capital costs	100	77
Variable costs		
Wind farm annual operation and maintenance (O&M) costs		1–1.5
Total 20-year project O&M costs		~23

Note: Estimates relate to onshore medium-sized (1.5–2.0MW) turbines. Table is a rough estimate and no attempt is made to bring fixed and variable costs to a directly comparable net present value (NPV) format.

Sources: European Wind Energy Association; National Renewable Energy Laboratory's (NREL) Job and Economic Development Impact (JEDI) model; authors' interviews.

Table 5 Major parts of wind industry value chains

Value chain segment			Key component characteristics	Degree of wind industry segment vertical integration
	R&D	Whole turbine design/ component design	Wind service	Mostly OEM inhouse; some specialist R&D/ IP service providers
"Upstream"	Key materials	Cast iron	Approximately 15–20 tons per installed MW. Used for several key components.	Overwhelmingly external suppliers
		Forgings	Approximately 10 tons per installed MW. Used for several key components.	Overwhelmingly external suppliers
		Reinforcement fibers	Glass fibers, carbon fibers, woven and stiched fabrics, pre-impregnated glass. Used in blades.	Solely external suppliers
"Manufacturing"	Components manufacturing	Towers	Ranges from 50m to 110m and weighs up to 280–300 tons, depending on tower classification. Usually ships in units no larger than 70 tons.	Some OEM Inhouse; mostly external suppliers.
		Blades and hub	Blades varies in length up to 60m. Each blade and hub shipped separately, with combined weight up 45 tons.	Mostly OEM inhouse; one major extrenal supplier with global presence.
		Gearboxes	Most wind turbine gearboxes are produced by a small number of large established external suppliers; top 3 = Winergy (owned by Siemens), Hansen (owned by Suzlon), and Bosch-Rexroth (independent)) with their own global production operations. The boom in wind power has led to a significant number of new entries into the gearbox industry, especially in Asia.	
		Generators	Most wind turbine generators are produced inhouse by OEM producers or by large suppliers of a broad portfolio of electrical machinery. China has seen the entry of a large number of new turbine suppliers in recent years.	
		Large bearings	Several types of bearings are a critical part of the several moving components of a wind turbine (gearbox, main shaft, yaw, pitch, and generator). All bearings are produced by large-scale external bearings suppliers with own global operations.	
		Power converters	Converts wind power into power grid frequency and voltage.	Some OEM inhouse; mostly external suppliers.
	Turbine manufacturing	Final turbine assembly	n.a.	Solely OEM inhouse
"Downstream"/ wind power production	Turbine deployment	Turbine marketing/sales	Wind service	Solely OEM inhouse
		Wind park site assessment	Wind service	External wind assessment consultancies
		Financing	Wind service	Large number of external banks and financial firms and consultancies
		Transport/logistics	Wind service	OEMs, relying on external providers of logistics services
		Wind park construction	Wind service	External providers of construction services
	Post-deployment services	Wind park operations and maintenance	Wind service	OEMs, independent power producers, and external utility companies
		Repowering and grid connections and wind power sales	Wind service	OEMs, independent power producers, and external utility companies

OEM = original equipment manufacturer
IP = Intellectual property

Sources: Table draws extensively on BTM Consult ApS (2008); European Wind Energy Association, www.ewea.org; American Wind Energy Association, www.awea.org; Vestas, GE Wind product specifications; authors' industry expert interviews in August/September 2009.

Table 6 Global trade in wind turbines (HS 8502.31) 2008

World exports		
Country	**Millions of US dollars**	**Share of global total** (percent)
Germany	2,004	41.3
Denmark	1,250	25.8
India	651	13.4
Japan	469	9.7
China	211	4.3
Portugal	122	2.5
Italy	24	0.5
United States	22	0.5
Australia	20	0.4
Other countries (47)	82	1.7
World imports		
Country	**Millions of US dollars**	**Share of global total** (percent)
United States	2,679	42.8
Germany	563	9.0
Canada	545	8.7
Britain	421	6.7
Turkey	285	4.6
Australia	221	3.5
Italy	204	3.3
China	189	3.0
Japan	174	2.8
Other countries (92)	972	15.5
Breakdown of 2008 US imports		
Exporting country	**Millions of US dollars**	**Share of US total** (percent)
Denmark	868	32.4
Spain	690	25.8
Japan	395	14.8
Germany	310	11.6
India	148	5.5
United Kingdom	138	5.2
Portugal	74	2.7
Italy	35	1.3
China	14	0.5
Other countries (17)	8	0.3

Source: UN Comtrade Database, http://comtrade.un.org.

Table 7 Breakdown of major wind turbine components by factor imputs(percent)

	Cost		
Component	Bulk raw materials	Labor	Other, including intellectual property
Tower	90	5–7	3–5
Nacelle/rotor hub	90	5–7	3–5
Blades[a]	60	25–30	10–15
Gearbox	80	5–7	13–15
Generator	80	5–7	13–15
Bearings	70	5–7	23–25

a. Significant fossil fuel cost in production.

Note: Bulk raw materials consist overwhelmingly of steel but also include permanent magnets, aluminum, copper, glass-fiber reinforced plastic, and carbon fiber reinforced plastic.

Sources: DoE (2008); authors' industry expert interviews, August/September 2009.

Table 8 Average MFN applied and bound duties for wind turbines (HS 8502.31), selected countries

Country	Average MFN applied duty	Average bound duty	Latest year of reporting
Argentina	0.0	35.0	2004
Australia	2.5	5.0	2009
Bangladesh	0.0	n.a.	2005
Brazil	0/(14)	35.0	2009
Canada	0.0	6.2	2009
Chile	6.0	25.0	2009
China	8.0	8.0	2008
Colombia	10.0	35.0	2009
Costa Rica	0.0	45.0	2009
Egypt	5.0	10.0	2007
EU-27	2.7	2.7	2008
India	7.5		2008
India	12.5	25.0	2006
India	25.0		2002
Indonesia	10.0	40.0	2007
Israel	0.0	9.2	2006
Japan	0.0	0.0	2008
South Korea	8.0	n.a.	2008
Malaysia	0.0	30.0	2001
Mexico	10.0	37.5	2009
Morocco	2.5	30.0	2002
New Zealand	2.5	16.5	2008
Philippines	1.0	20.0	2008
Taiwan	10.0	10.0	2008
Thailand	10.0	n.a.	2007
United States	1.3	1.3	2008

n.a. = not available

MFN = most favored nation

Note: There is no change in the bound tariff levels for India from 2002 to 2008.

Source: World Trade Organization Integrated Data Base notifications, www.wto.org.

Table 9 Average employment generation over lifespan of facility (jobs per gigawatt hour of power produced)

Energy Source	Manufacturing, construction, and installation	Operations and maintenance/ fuel processing	Total	Project average
Solar photovoltaic	0.16–0.84	0.07–0.57	0.23–1.42	0.87
Biomass	0.01–0.03	0.16–0.21	0.19–0.22	0.21
Wind power	0.03–0.14	0.05–0.13	0.1–0.26	0.17
Coal-fired	0.03	0.08	0.11	0.11
Natural gas-fired	0.01	0.1	0.11	0.11

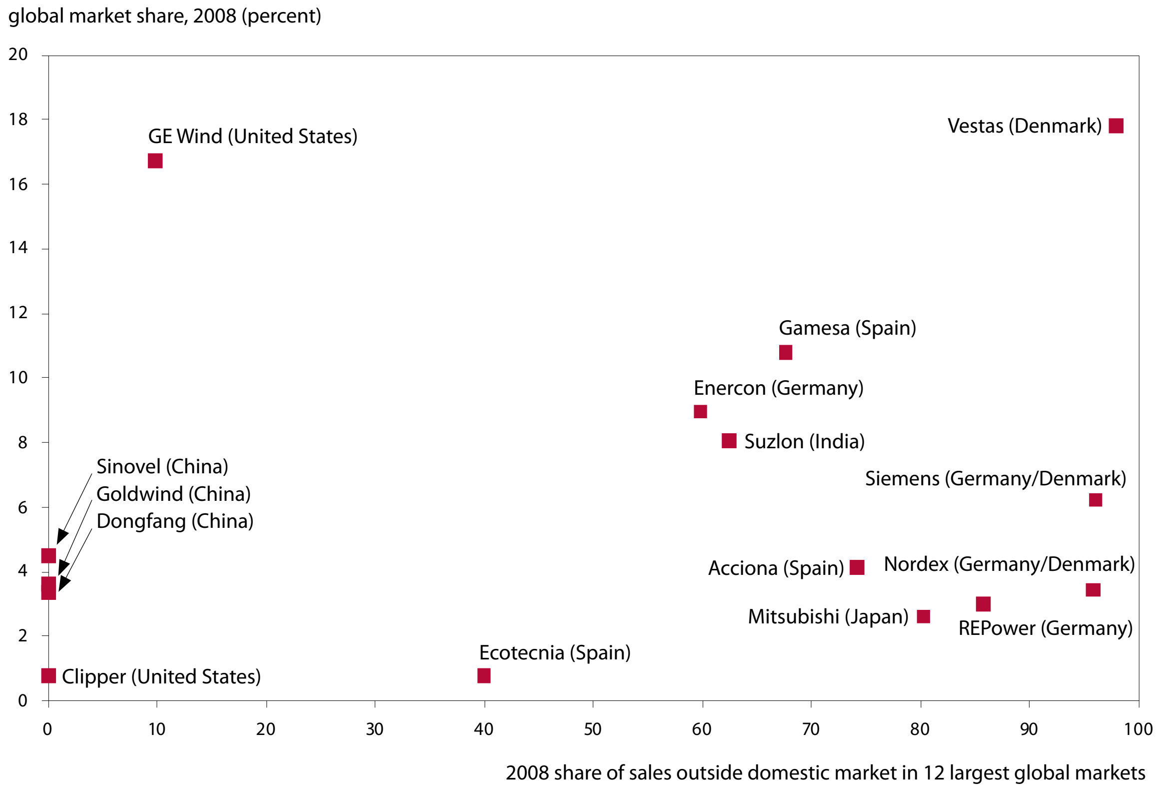
Note: The data are average annual employment numbers distributed over the lifespan of an installation and takes into consideration the very different factor capacities of renewable (low factor capacities) and fossil fuel (high factor capacities) energy sources.

Source: Wei, Patadia, and Kammen (2009).

Table 10 Estimates for employment in the wind energy industry

	Global	Europe	United States	China
Wind industry jobs	350,000–400,000	155,000	85,000	22,000
Share of manufacturing jobs (percent)	n.a.	66	25	66
Data source	Global Wind Energy Council, www.gwec.net	EWEA (2009c)	AWEA (2009c)	UNEP et al. (2008)

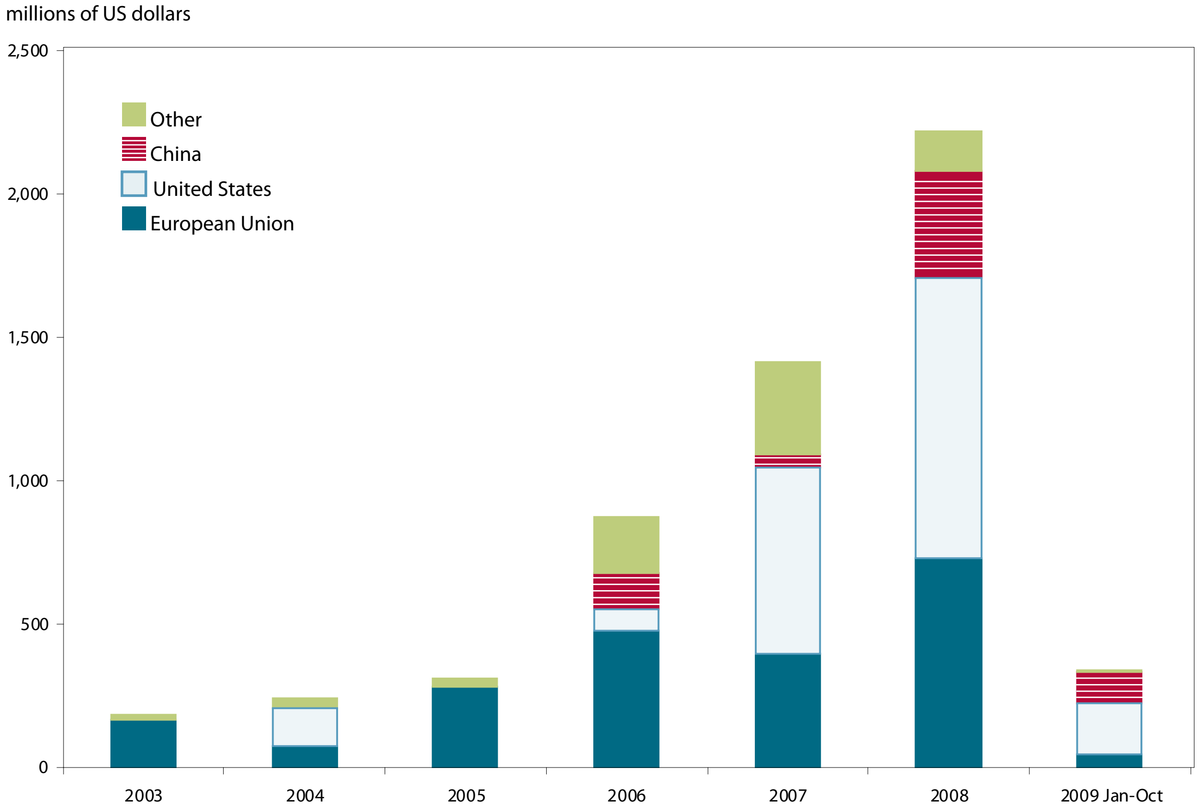
Figure 1 Top 15 wind turbine original equipment manufacturers' major market presence, 2008



Note: Data for 12 markets include Australia, Canada, China, France, Germany, India, Italy, Netherlands, Portugal, Spain, United Kingdom, and United States. Nondomestic sales share for Vestas and Mitsubishi determined from company annual reports available at their websites.

Source: BTM Consult ApS (2009); Mitsubishi Power Systems, www.mpshq.com; Vestas, www.vestas.com.

Figure 2 Greenfield investments in wind turbine production, 2003–09



Note: Data include both actual and estimated costs for announced project costs.

Source: fDi Markets Project Database, www.fDiIntelligence.com.