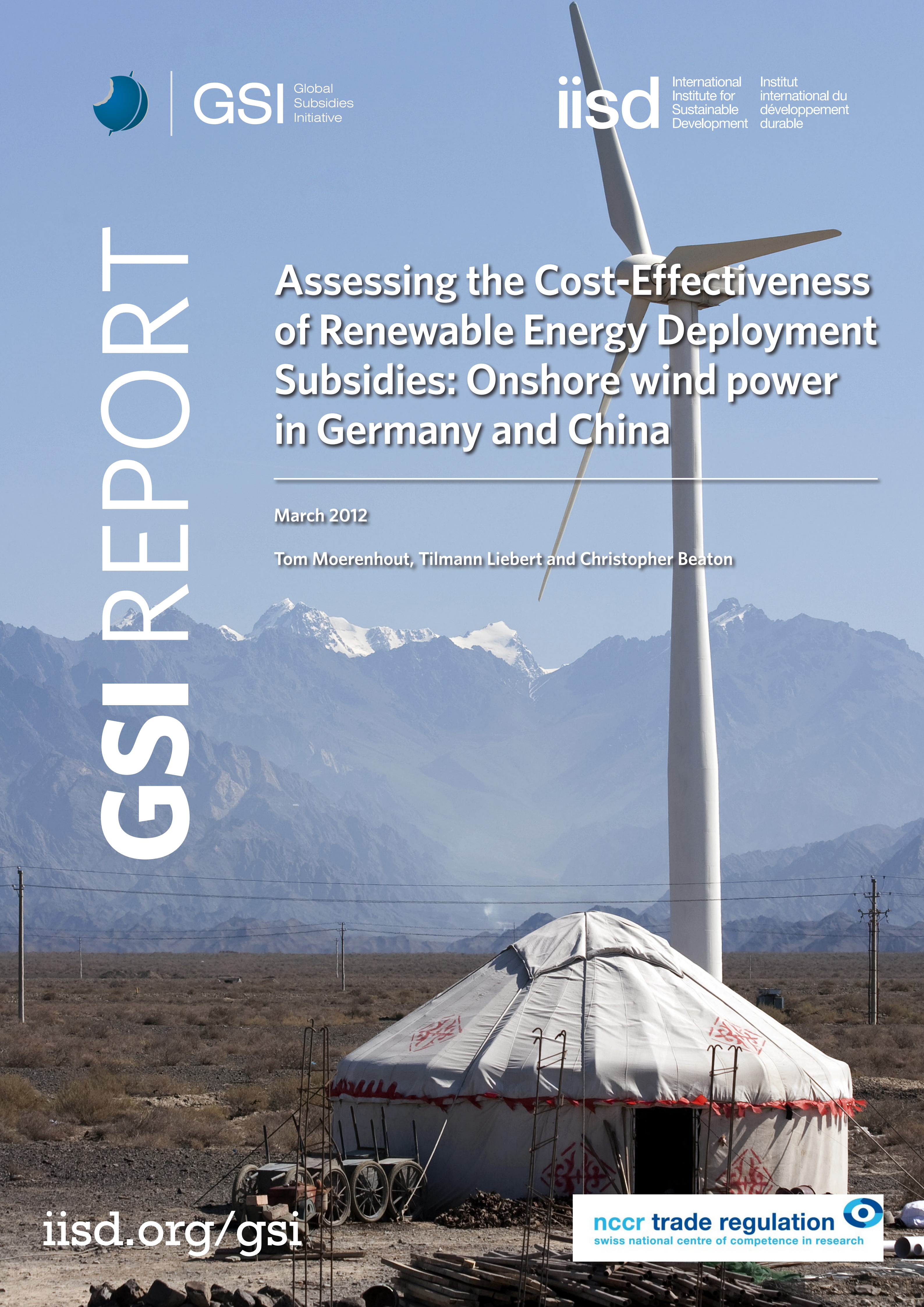

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GSI REPORT

Assessing the Cost-Effectiveness of Renewable Energy Deployment Subsidies: Onshore wind power in Germany and China

March 2012

Tom Moerenhout, Tilmann Liebert and Christopher Beaton

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Head Office
161 Portage Avenue East, 6th Floor, Winnipeg, Manitoba, Canada R3B 0Y4
Tel: +1 (204) 958-7700 | Fax: +1 (204) 958-7710 | Website: www.iisd.org

About GSI

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International Institute for Sustainable Development
Global Subsidies Initiative
International Environment House 2, 9 chemin de Balexert, 1219 Châtelaine, Geneva, Switzerland
Tel: +41 22 917-8373 | Fax: +41 22 917-8054

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Acknowledgements

This study forms one of a series of three looking at the cost-effectiveness of renewable energy deployment subsidies, each one focusing on different technologies and countries. The increased deployment of low-carbon energy is one of the principal interventions required to avoid catastrophic climate change. At the same time, the success of deployment will depend upon government policy that is effective and that uses resources efficiently. This is central to maximizing the amount of renewables deployed given the resources that are available, and to ensuring that subsidies for renewables remain politically viable. These studies represent a first effort to develop an appropriate multi-criteria framework for evaluating the cost-effectiveness of renewable energy subsidies, taking into account all costs and the wide range of potential benefits. The evaluation of subsidy policies is a core function of the Global Subsidies Initiative (GSI) and this methodology will continue to be developed in the coming years. If you have any comments, questions or recommendations, please contact us via our website, http://www.iisd.org/gsi.

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1.0 Introduction

In the last decade, a growing number of countries have employed subsidies to increase the deployment of renewable energy technologies. The subsidies have been credited with a wide range of positive outcomes, such as carbon reductions and job creation, and some advocate that more countries around the world should introduce similar schemes. The policies have also attracted critics, who question whether the subsidies are the best way to achieve the stated policy objectives and whether the costs can be justified. This paper explores how policy-makers might go about assessing the cost-effectiveness of subsidies to onshore wind energy. How can they assess subsidies to the industry? How can they measure the benefits that are achieved and assess their value?

In considering these methodological questions, this paper explores deployment subsidies in two countries: Germany, a developed economy and one of the first to make significant investments in the wind industry, and China, an emerging economy and a relative late-comer to the wind industry, which has nonetheless acquired large shares of the global market in recent years.

As an exploratory paper, this study is unable to draw confident conclusions about cost-effectiveness. Its goal is to explore the methods required to assess cost-effectiveness and to estimate the general magnitude and range of benefits in several key areas.

2.0 Methodology

This study explores the cost-effectiveness of deployment subsidies for wind energy in Germany and China in two steps. First, it tries to estimate the effectiveness of a prominent subsidy in each country—that is, the extent to which the subsidy has achieved its policy objectives and the value of these benefits. Second, it estimates the economic costs of the policies. A comparison of the two then allows for a discussion of whether the outputs and outcomes have been achieved at a "reasonable cost."

Germany's main support mechanism for onshore wind is a feed-in tariff: a subsidy mechanism whereby renewable energy producers are guaranteed a fixed price for a set number of years. It was first established in 1990 with the Stromeinspeisungsgesetz (StrEG). The StrEG was replaced in 2000 by the Renewable Energy Sources Act (Erneuerbare-Energin-Gesetz [EEG]). Germany provides a number of supplementary support mechanisms for renewable energy too, but this study considers only the EEG in the period 2000–2010.

In 2000 Germany had already generated 7.5 terawatt-hours (TWh) from onshore wind energy. By 2010 this had risen to 37.6 TWh. In the same period, installed capacity grew from 6.10 gigawatts (GW) to 27.20 GW—a total increase of 21.11 GW (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit [BMU], 2011d). Assuming that the majority of German wind capacity would not have been installed without financial support, it is reasonable to conclude that the EEG has succeeded in stimulating deployment.

In China, two parallel processes have been used to develop national wind power capacity between 2003 and 2009: a "concession project" tendering system and a "government-approved" tariff system. Due to perceived shortcomings, both systems were abandoned in 2009 with the introduction of a national feed-in tariff (Global Wind Energy Council, 2010c). A number of provinces have also organized their own support mechanisms for wind energy, including bidding rounds and feed-in tariffs (Hu, Shi, & Li, 2010). Due to the difficulty of accessing sufficient data about most regimes, this study considers only the smallest of the three, the concession tendering system.

From 2003 until 2007, the concession tendering system selected 18 projects across five bidding rounds. This represented a total installed capacity of 3.35 GW (10 per cent of overall 2009 capacity, but just 2 per cent of overall 2010 capacity) (Shi, 2008). Assuming that all 18 were connected to the grid, and that average full-load hours in each province are equal to those reported in 2007 by Shi (2008), they can be expected to produce together roughly 130,000 gigawatt-hours (GWh) over 20 years. It should be emphasized that the support received under the concession tendering system is not representative of the average support provided to wind power in China (e.g., under the feed-in tariff system introduced in 2009); caution is therefore urged in extrapolating findings on the concession tendering system to another capacity.

The following analysis considers all capacity added between 2000 and 2010 in Germany, and the specific projects awarded a concession in China. It is assumed that the life of an installation is 20 years. In conducting the analysis, all monetary values were expressed in constant values, before discounting at a 3 per cent real discount rate. The base year for the analysis is 2010.

3.0 Effectiveness

The common objectives that governments set out to achieve through subsidies for renewable energy deployment, broken down into intended outputs and outcomes, are listed in Table 1. This section estimates the impacts that renewable energy subsidies have had on these objectives.

TABLE 1: DEPLOYMENT SUBSIDIES FOR RENEWABLE ENERGY TECHNOLOGIES (RETS): A SUMMARY OF POLICY OBJECTIVES, INTENDED OUTPUTS AND INTENDED OUTCOMES

POLICY OBJECTIVES	INTENDED OUTPUTS	INTENDED OUTCOMES
Environmental goals: • Mitigation of climate change • Reduction of local pollution	Increased deployment of renewable energy	Renewable energy generation will offset carbon-intensive energy sources, resulting in less carbon dioxide emissions and reduced local air pollution.
Economic and social goals: • Industry creation • Job creation • Regional development		Increasing deployment of renewable energy technologies can: • Foster national industries, creating jobs in manufacturing, installation and maintenance, and allowing for the export of RETs and related services • Allow for the export of renewable energy to other countries By influencing the location of investments, this economic wealth can promote the development of specific regions.
Energy security goals: • Increased energy security		Increasing the share of renewable energy will increase the diversity of the energy supply mix, making a country less reliant on other sources of supply, notably imported fossil fuels.
Development of RETs: • Cost reductions		According to “learning-by-doing” models, as a rough rule of thumb costs will be reduced by a fixed percentage every time the installed capacity of a renewable energy technology doubles. Market support for RETs will also stimulate private investment in research and development (R&D). These cost reductions will, in turn, lead to increased deployment of RETs, contributing to all three of the outcomes listed above.

In support of the general objectives listed in the table above, some countries state a specific target for the increased deployment of various RETs and occasionally state targets for specific outcomes too—for example, absolute or relative amounts of wind technologies deployed by a certain date, specific reductions in carbon dioxide emissions or ambitions for job creation. In this analysis, specific targets were not considered. Effectiveness was identified as the impacts of the policy with respect to each of the general objectives listed above, regardless of the prominence accorded to them in the underlying legislation. The specific priorities of Germany and China are, however, taken into account in interpreting the data.

The analysis then moves to assess cost-effectiveness by estimating, where possible, the economic value of the achieved benefits compared to the estimated financial burden of the subsidies.

3.1 Environmental Goals

3.1.1 Environmental Impacts

Wind energy can contribute to reducing greenhouse gas (GHG) emissions by supplanting energy technologies with higher carbon intensity. The site- and country-specific emissions reductions that can be achieved by deploying wind energy depend on several factors: the type of energy that is replaced, the source and amount of energy consumed during the life cycle of the installation, and an installation's performance characteristics. At low levels of penetration, wind energy is most likely to replace electricity from sources that are not needed to provide base load supplies and are operating at the cost margin—usually gas or coal-based technologies. The benefits of this can be measured in various ways. One is to directly estimate the amount of carbon dioxide that is emitted per kilowatt-hour (kWh) or megawatts (MW) of wind power compared to displaced energy technologies. The IPCC Special Report on Energy Sources and Climate Change Mitigation (SRREN) reports that the majority of life-cycle estimates for equivalent carbon emissions, including construction, operation and decommissioning, from wind power are between 8 and 20 grams of CO_2 equivalent (gCO_2e)/kWh, with the highest placed at 80 gCO_2e/kWh (Wiser, et al., 2011). An alternative measure is energy payback time, which indicates how long it will take a power plant to generate the amount of energy that was used in its manufacturing, installation, operation and decommissioning. According to the Intergovernmental Panel on Climate Change (IPPC), most estimates of the average energy payback time for wind energy are between 3.4 and 8.5 months (Wiser, et al., 2011). Although not emission-free, wind energy can thus considerably reduce GHG emissions.

Wind power can also reduce other fossil-fuel emissions that are harmful to human health and the environment, such as nitrogen oxide, sulphur dioxide, mercury emissions, volatile organic compounds and heavy metals (Jacobson & High, 2008). The potential gains are likely to be greatest in countries where standards for air quality and fuel combustion are low. In China, for example, urban air pollution is severe in a number of cities, posing significant health risks (Wong, 2011a, 2011b). Where fossil-fuel-based electricity generation plays a role in creating such pollution, its displacement by wind power could provide significant benefits. A report by the International Energy Agency (IEA, 2011c) provides a comparison of emissions from renewable and non-renewable technologies for two local pollutants (nitrogen oxide and sulphur dioxide). The report finds that, with the exception of biomass, renewable energy technologies have much lower emissions than fossil-fuel energy sources. Although it was only possible for this exploratory study to estimate the volume and value of offset GHG emissions, these other benefits should be taken into account by any comprehensive assessment of cost-effectiveness.

3.1.2 Estimating Offset Carbon Emissions

A country-specific emissions saving factor can be calculated by taking the difference between the average emissions for wind from the average emissions for the energy production technologies being displaced in a given country. The displaced technologies will usually be a combination of coal- or gas-based generation.

In Germany, the objectives of the EEG include the management of global warming, protection of the environment, incorporation of long-term external effects and facilitation of a sustainable energy supply (Government of Germany, 2000). As a member of the European Union (EU), its policies are also supposed to meet the objectives of the EU's renewables policy, which includes climate change mitigation and sustainable development (European Commission, 2009). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has estimated an emission savings factor of 736 g CO_2e/kWh (BMU, 2011a), based on studies of the carbon dioxide equivalent involved in the life cycle of wind power in Germany and data on the energy technologies most commonly being offset by wind. In 2008 and 2009, 6 per cent of wind power is reported to have displaced lignite power plants, 64 per cent to have displaced hard coal and 30 per cent to have displaced natural gas (BMU, 2011b). It was assumed that this factor was consistent through the years of wind power installments under the scheme. As factors vary year by year, this will affect the accuracy of estimates.

As a non-Annex I country, China has no binding GHG emission reduction targets. Nevertheless, under the United Nations Framework Convention on Climate Change (UNFCCC) process, the country has committed to a 40–45 per cent reduction in carbon intensity (carbon dioxide emissions per unit of GDP) by 2020 compared to 2005. This is mirrored in the 2011–2015 Five-Year-Plan, which mandates a 17 per cent reduction in emissions by 2015. The largest grid operator, State Grid, has committed to reducing carbon dioxide emissions by 10.5 billion tonnes during the current decade through smart grid technologies (China Daily, 2010). Emission savings factors for wind power and information on displaced energy sources are not as readily available for China as for Germany. Estimates were therefore calculated using an average wind emissions factor of 14g CO_2/kWh—the midpoint of the range reported by the IPCC. As an upper bound, it was assumed that all energy offset was based on coal, and as a lower bound, that all energy offset was based on gas. Using IEA data on the carbon dioxide intensity of coal and gas in China (IEA, 2011a), this resulted in an emissions savings factor of 417–886 g CO_2e/kWh. Given the very prominent role of coal in China's electricity system—in 2009 it produced 66.7 per cent of the country's electricity, compared to only 1.7 per cent from gas (IEA, 2011d)—it is likely that the true figure is toward the upper end of this range. Estimates of emissions savings in China and Germany cannot easily be compared under these assumptions, as Chinese emissions savings are not stated in the units of carbon dioxide equivalent.

Savings are estimated for the period in which current data is available about each policy (2000–2010 for Germany; 2003–2010 in China) and up until the lifetime of currently installed capacity, assumed to be 20 years from the first year of generation. Because there are different levels of uncertainty in the emissions factors and assumptions made in each country, caution is urged in comparing the estimates.

It is difficult to assess the value of emission offsets, as no consensus exists about the "right" price for carbon. Prices also change with time, as cheaper mitigation options are exhausted. This study looked at existing and projected prices for emission trading schemes in order to assign a financial value to the carbon offset. As a lower band, the EU Emission Trading System (ETS) price of carbon was used. This has never reached higher than €35 per tonne and has generally remained below €15 per tonne since the scheme was launched (Environmental Audit Committee, 2010), at some points with a value of close to zero. For a medium and high band, values were derived from integrated assessment models of the emissions cost needed to limit carbon dioxide levels to 550 parts per million (ppm), from sources whose estimates ranged from US$135 to $380 (€105–€295) by 2060 (IMF, 2008). For the purposes of analysis, low, medium and high values of €15, €50 and €200 were assigned to indicate the range of possible carbon values. The variance between the values reflects differing opinions as to the damages that should be expected from climate change and the appropriate way to place value on future costs.

In Germany, it should also be noted that the EU ETS co-exists alongside the EEG. This has led to criticism that renewable energy subsidies have simply reduced the price of carbon under the ETS and so prevented emissions being achieved more cheaply elsewhere in the EU. This study assumes no such effect and assesses the value of carbon reduced assuming no leakage.[1] In China, it should be noted that this analysis only includes wind power installed under the concession scheme, approximately 10 per cent of Chinese wind capacity up to 2010, so it should not be taken as representative of the entire market. The estimate is likely to be slightly under the true value, taking into account that the German figure contains not only carbon dioxide but other GHGs expressed as carbon dioxide equivalent, while the Chinese figure refers only to carbon dioxide. Nevertheless, as carbon dioxide is the main GHG resulting from coal production, the difference is unlikely to greatly alter the analysis.

[1] For a more in-depth discussion of this potential complication, see the report on solar PV systems in this series on subsidies to renewable energy (Bridle & Beaton, 2012), as well as Philibert (2011).

TABLE 2. CARBON OFFSETS IN GERMANY AND CHINA

	GERMANY		CHINA (CONCESSION TENDERING SCHEME ONLY)[1]	
	SAVINGS FROM 2000–2010	SAVINGS OVER LIFETIME OF CAPACITY INSTALLED IN 2000–2010	SAVINGS FROM TENDERING, 2003–2010	SAVINGS OVER LIFETIME OF TENDERING CAPACITY INSTALLED IN 2003–2007
Total CO_2 savings[2] (m. tonnes)	175.0	684.2	9.2–19.5	53.8–114.3
Value of carbon saved (€ billion)				
At €15 / tonne	2.9	8.9	0.14–0.31	0.81–1.73
At €50 / tonne	9.7	29.7	0.48–1.02	2.71–5.76
At €200 / tonne	38.8	119.0	1.92–4.08	10.84–23.03

[1] Note: due to difficulties accessing data, estimates pertain only to wind power installed through China's concession tendering scheme. They do not include carbon offset by wind power installed through the government-approved tariff scheme or the 2009 feed-in tariff. They therefore apply to only around 10 per cent of total installed capacity in 2009 and 2 per cent of total capacity in 2010.

[2] Note: estimates for Germany are in CO_2 equivalent; estimates for China are CO_2 only.

The estimates indicate that wind energy has made a significant contribution to reducing carbon emissions, amounting by 2010 to 175 million tonnes through the German feed-in tariff scheme (based on the BMU displacement factor), and 9.2 million–19.5 million tonnes through the 3.35 GW of capacity installed under the Chinese concession tendering scheme (low estimate based on displacing gas, high estimate based on displacing coal). In absolute terms, the estimate of Germany's savings is necessarily higher than China's because of the much larger volume of installed capacity under the EEG than China's concession tendering scheme, the only Chinese support policy for which sufficient data was available to derive an estimate. In relative terms, it is difficult to determine which country achieves higher savings per unit of installed capacity, due to the large range of uncertainty in the appropriate avoidance factor for the sector in China.

3.2 Economic Goals

A common justification for government support to environmental technologies such as wind power is their contribution to sustainable economic growth. This follows from expectations for "green" technologies and markets to see increasing demand in coming years, especially as the costs of renewable energy technologies fall. A broad survey of businesses and research institutions by the consultancy firm Roland Berger (2010), for example, estimates that the global market volume for environmental technologies will grow from €1.4 trillion in 2007 to €3.1 trillion in 2020. Through economic modelling, the United Nations Environment Programme (UNEP) has argued that the "greening" of economic sectors—which includes a significant increase in the volume of renewable energy—would, in the medium and long terms, raise economic growth and employment compared to a business-as-usual scenario (UNEP, 2011). According to a recent review of studies by the International Renewable Energy Agency (IRENA), total gross jobs in renewable energy have grown significantly in the past decade—estimates range from 1.3 million to more than 3.5 million jobs between 2004 and 2010 (Greenpeace, 2009; REN21, 2011, as cited in IRENA, 2011).

Subsidies for renewable energy are often intended to help countries acquire or increase such benefits. Often, the aim is to stimulate the development of a national industry that can secure a portion of the international market once costs fall and more countries begin to deploy the technology. Alternatively, countries may simply target the jobs involved in the construction and maintenance of national capacity. This section considers the extent to which Germany and

China have succeeded in promoting internationally successful wind turbine manufacturers and the extent to which they have stimulated the creation of employment due to their support for wind power.

3.2.1 Benefits from Manufacturing

Many policies explicitly promote the establishment of manufacturing bases in renewable energy technologies. In Germany, the EU's Renewable Energy Directive includes an objective of developing an innovative renewable energy industry to generate jobs and wealth (European Commission, 2009). In China, one of the primary objectives of the Renewable Energy Law is to promote the domestic renewable energy industry and support regional economic development (National People's Congress, 2005). Both countries can be deemed successful in their endeavours. In its recent Country Attractiveness Index for wind energy, the advisory firm Ernst and Young (2011) ranked China first and Germany second out of 35 countries, in part based on their attractiveness for developing projects. To what extent can this be attributed to subsidies?

According to a WWF study examining the development of clean energy technologies, three factors are crucial to industrial success: first, early and steady government support throughout the full innovation cycle; second, high investment in the sectors that emerged as successful with government support; and third, strong domestic markets for cleantech (van der Berg & van der Slot, 2009). In light of these arguments, Germany's leadership in wind power is unsurprising. Like Denmark, it is a first mover in the technology, having provided sustained support for research and development over many years, as well as deployment policies that have created a significant domestic market in the early years of the industry. Although its industrial expansion is unlikely to have taken off without subsidies, the extent of its success is also likely to derive from its general economic competitiveness in sectors requiring scientific and technical innovation.

In the past decade, Chinese firms have swiftly risen to become leaders in the wind industry too. In 2004, when German firms made up 27.7 per cent of the global wind turbine market, no Chinese companies numbered among the top 10. By 2009, three Chinese companies had emerged among the world's top 10 manufacturers, with a combined share of almost 25 per cent. By 2010 this had increased to four companies with a combined share of almost 32 per cent. While the global market size increased considerably between the two years, and therefore the sector as a whole enjoyed an unparalleled boom, the change in relative competitiveness is considerable.

TABLE 3. TOP 10 WIND TURBINE MANUFACTURERS IN TERMS OF GLOBAL SHARE OF NEWLY INSTALLED CAPACITY

	2004			2009			2010		
1	Vestas	–	34.1%	Vestas	–	12.5%	Vestas	–	14.8%
2	Gamesa	–	18.1%	GE Energy	–	12.4%	Sinovel	–	11.1%
3	Enercon	–	15.8%	Sinovel	–	9.2%	GE Energy	–	9.6%
4	GE Wind	–	11.3%	Enercon	–	8.5%	Goldwind	–	9.5%
5	Siemens	–	6.2%	Goldwind	–	7.2%	Enercon	–	7.2%
6	Suzlon	–	3.9%	Gamesa	–	6.7%	Suzlon	–	6.9%
7	REpower	–	3.4%	Dongfang, DEC	–	6.5%	Dongfang, DEC	–	6.7%
8	Mitsubishi	–	2.6%	Suzlon	–	6.4%	Gamesa	–	6.6%
9	Ecotecnia	–	2.6%	Siemens	–	5.9%	Siemens	–	5.9%
10	Nordex	–	2.3%	* REPower	–	3.4%	Guodian United Power	–	4.2%
Total share German firms		–	27.7%		–	14.4%		–	13.1%
Total share Chinese firms		–	0%		–	22.9%		–	31.5%

** REPower was acquired by Indian manufacturer Suzlon in 2007.*

Data sources: BTMConsult in REPower systems (2005); ekopolitan (2011).

Although China started its government support for wind energy considerably later than Germany, it is still a relatively early mover in global terms. One of the most important factors behind China's strong international performance has been the growing dominance of Chinese companies in its very large domestic market, driven by deployment subsidies. China is endowed with a strong domestic market for wind power: it is the country with the largest cumulative installed capacity of wind power in the world, having increased its capacity from 0.6 GW in 2002 to 44.7 GW by in 2010 (Li, Cai, & Tang, 2011). It also holds much potential for further growth, with national onshore and offshore wind power capacity being estimated at around 700–1,200 GW (Hu, Shi, & Li, 2010). Figure 1 shows the extent to which the market share of newly installed capacity has, since 2004, dramatically shifted toward Chinese manufacturers.

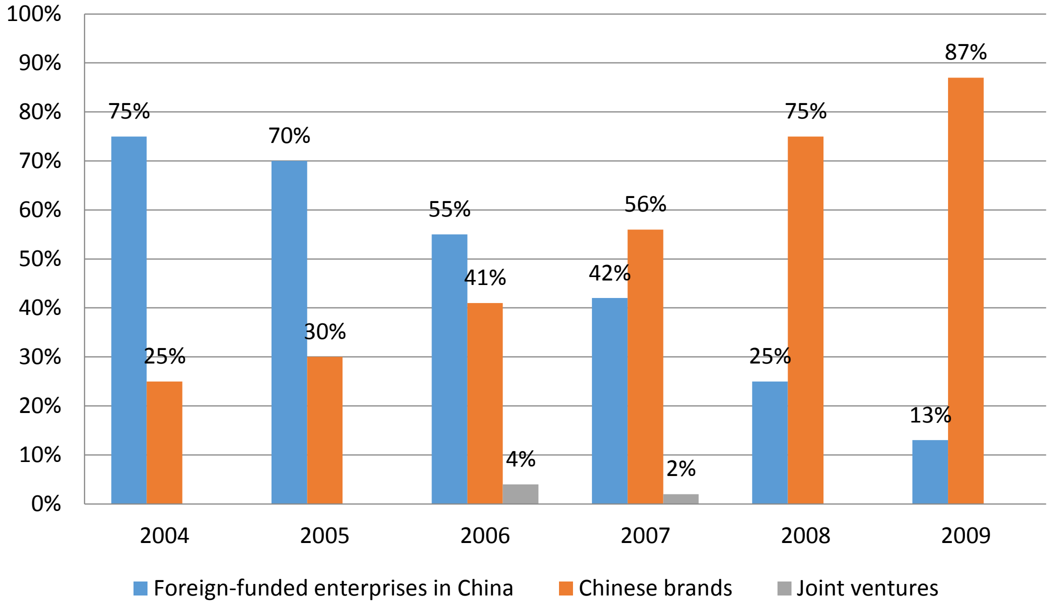

FIGURE 1. MARKET SHARE OF DOMESTIC AND FOREIGN FIRMS IN SUPPLYING NEWLY INSTALLED CHINESE WIND POWER CAPACITY

In addition to creating a large domestic market, the specific design of China's deployment subsidies is likely to have played a role in stimulating its national industries. In its concession tendering regime, bidders were required to source a minimum percentage of their supplies locally—thus guaranteeing that financial support would largely benefit national manufacturers. The key criteria used in each round are summarized in Table 4. Although this study is focused on China's concession tendering regime, it should be noted that other support schemes—some of which might apply to tendered wind farms—have also included design elements that benefit national companies. In order to qualify for official Clean Development Mechanism (CDM) projects, for example, the Chinese government required that at least half of each wind power company had to be Chinese-held (Recknagel, 2010). Similarly, in 2008 the Chinese government's Special Fund for the Wind Power Manufacturing Sector required that "wind turbine component of blades, gearboxes and generators [had to] be manufactured by Chinese companies or Chinese controlled stock companies" in order for companies to qualify for its support for R&D activities (Ministry of Finance, 2008). Other requirements included that the technology in question be in an early stage of development and that the equipment was covered by Chinese intellectual property rights.

TABLE 4. REQUIREMENTS IN DIFFERENT BIDDING ROUNDS OF CHINESE CONCESSION TENDERING SCHEME

BIDDING ROUND	WEIGHT OF BIDDING PRICE	CRITERIA
1. (2003)	100%	Localization rate > 50%
2. (2004)	100%	Localization rate > 70%
		Single generator capacity > 600 kW
3. (2005)	40%	Localization rate > 70%
		Single generator capacity > 600 kW
4. (2006)	30%	Localization rate > 70%
		Single generator capacity > 750 kW
		Bidders have to select their equipment manufacturers before the bidding process and are not allowed to change if they win.
5. (2007)	25%	Rather than the lowest bidding price, bidders are scored highest if they are closest to the average bid price, to disincentivize under-bidding Localization rate > 70% (weight 35%).
		Single generator capacity > 750 kW (weight 20%)
		Bidders have to select their equipment manufacturers before the bidding process and are not allowed to change if they win.

Source: Li et al. (2007)

Such explicit preferential treatment for domestic firms is not uncontroversial. Reacting to a petition by the United Steelworkers union in September 2010, the United States Trade Representative (USTR) initiated an investigation in October 2010 to examine allegations that the Chinese government was providing support to clean energy technologies that favoured domestic over imported goods—thus contravening the World Trade Organization (WTO) Agreement on Subsidies and Countervailing Measures (ASCM). The original petition addressed all policies affecting steel inputs into clean energy technologies and thereby also the Special Fund for Wind Power Manufacturing Sector established in 2008. The USTR estimated that the fund had disbursed "several hundred million dollars" in total through individual grants—between US$6.7 million and $22.5 million. The United States held consultations with China at the WTO in February 2011 and after their conclusion in June 2011, China formally revoked the Special Fund program (USTR, 2011).

China is not the only country that has been challenged over local content requirements in renewable energy subsidies. In September 2010 Japan started dispute settlement proceedings against Canada for a feed-in tariff policy in Ontario, which allegedly favours domestic firms through a localization rate of 60 per cent (WTO, 2010). In August 2011 the European Commission lodged an official complaint with the WTO over the same policy. As of the beginning of 2012, a panel has been established and joint hearings will soon take place to discuss the issue.

In addition to international objections to domestic content requirements, it should also be noted that they may not by themselves be able to substitute for long-term investments in technology development and capacity building. According to Li et al. (2011), the Chinese government's emphasis has largely focused on a quick scaling-up of production, diverting resources from the R&D that is required to ensure a globally competitive standard in terms of quality. In recognition of this problem, Chinese companies have recently begun increasing investment in R&D, with all top 10 enterprises in the country now having established their own R&D centres with emphasis on developing self-owned technologies (Hu, Shi, & Li, 2010).

3.2.2 Employment Benefits

According to the Global Wind Energy Council (2010a), 600,000 people were employed in the global wind energy sector in 2009. Job creation is a commonly measured indicator for the economic benefits of subsidies to wind energy deployment. Estimates of gross job creation in Germany and China are relatively easy to identify. These can be used to estimate employment factors for wind energy in each country and job years across the lifetime of each policy. In reality, some jobs in the wind industry will be related to exports, and may in fact exist because of subsidy policies in the countries where the exports are destined. For the sake of simplicity, it is assumed that all jobs in the renewable energy sector in each country can be attributed to the deployment policy in question. As some jobs (such as construction) may be short term and other jobs (such as operations and maintenance) may be long term, all estimates are stated in job years—the amount of employment required to keep one person employed for the duration of a single year.

According to the BMU (2010b), total employment in the German wind sector rose from 63,900 in 2004 to 102,100 in 2009, a 160 per cent increase. This fell slightly to 96,100 in 2010 (BMU, 2011c). In 2009, around 70,000 of the jobs were provided by investment (including export) and the remaining jobs were in operation and maintenance (BMU, 2010b). Other sources report that around 35,000 of the jobs were in the production of wind turbines or their components (VDMA & BWE, 2010).

To estimate jobs across the lifetime of the EEG, it is necessary to derive three employment factors: job years per MW of newly installed national capacity; job years per MW of capacity produced for international trade; and jobs per year for the operations and maintenance of each MW of installed capacity. Based on European Wind Energy Association (EWEA, 2009b) estimates of the share of employment allocated across different stages of the wind industry, and assuming that manufacture for international trade only involves jobs in component manufacture, turbine manufacture, consultancy and R&D, this study estimates that around 16.25 jobs are created in Germany per national MW of capacity and 13.75 jobs per MW produced for trade. The EWEA's estimate of an annual 0.4 jobs per MW was then used to estimate jobs in operations, maintenance and other long-term employment. Assuming that all new national capacity was produced by German manufacturers and that all remaining production implied by estimates of German market share were intended for export (EWEA, 2003; REPower Systems, 2005; BTMConsult, 2008; ekopolitan, 2011), this indicates that 664,569 job years would have been created in the wind industry in the period 2000–2010, taking into consideration turbine production for German capacity and for trade. The 21.1 GW capacity installed in the period 2000–2010 will provide an additional 167,877 job years in operations and maintenance across its lifetime, assuming an average wind farm will operate for 20 years. These are likely to be slight under-estimates, as the EWEA's employment factors estimate 3 per cent less job years than those officially reported by the BMU in the period 2007–2010.

In China, job creation is not mentioned as an explicit objective of the Renewable Energy Law (National People's Congress, 2005). Nevertheless, the development of the country's wind sector has had notable employment effects. According to the *2010 China Wind Power Outlook*, around 150,000 people were directly employed in the Chinese wind sector in 2009. Together with indirect jobs, the number rises to around 200,000 (Hu, Shi, & Li, 2010). As it is not clear to what extent this estimate is broken down across new installations and operations and maintenance, it is not possible to extrapolate the number of jobs that were related to the 3,350 MW of capacity installed under China's concession tendering regime. Lacking an equivalent of the EWEA's estimates in Asia, this study assumes the same employment factors exist in China as in Germany. This assumption may underestimate Chinese employment, due to greater labour productivity in Europe. Assuming that all Chinese capacity under the regime was supplied by Chinese manufacturers, and that production for trade has been negligible, this indicates that the concession regime created a total of 55,500 job years in the period 2003–2010. The total installed capacity will provide an additional 23,500 job years in maintenance operations across its lifetime, assuming an average wind farm will operate for 20 years. These estimates are likely to be biased slightly upwards, as the EWEA's employment factors estimate 2.7 per cent more job years than those officially reported in 2009.

Although these estimates indicate marked success in gross job creation, caution should be exercised in their interpretation. A comprehensive cost-effectiveness analysis should ideally estimate the net impacts of wind power subsidies—not only gross. Net job estimates would take into account not only the jobs created by renewable energy but also the jobs that have not been created as a result of opportunity costs. For example, funds directed to the wind sector cannot be used for other purposes, reducing economic activity elsewhere. Feed-in-tariff schemes, such as the one in Germany, are often financed through higher charges to electricity consumers, reducing household purchasing power and affecting the profitability of energy-intensive industries.

Due to the complexity of estimating net job impacts—requiring complex economic modelling, and even then relying on many assumptions—this study is only able to estimate gross job creation. Given the likelihood that numerous negative impacts have not been accounted for, its figures should be treated as a highly optimistic "upper bound" of the possible employment gains from support for wind power in Germany and China. This is clearly illustrated by a modelling exercise conducted for the European Commission (Ragwitz, et al., 2009) based on policies in place in 2005, which estimated the net employment gain for Germany with respect to *all* renewable energy technologies—not just wind. The study used two macro-economic models (NEMESIS and ASTRA) and compared the results. In one model, job creation in Germany was estimated at around 25,000–33,000 jobs for all renewables by 2020, with the higher range representing an "optimistic exports" scenario. GDP was projected to grow by 0.10–0.14 per cent compared to a no-policy scenario. In a second model, the project estimated that there would be a net loss of employment in Germany of around 10,000 jobs by 2020, although GDP gains were still projected at 0.1 per cent. The increased cost of electricity was identified as a significant factor in counter-balancing the economic benefits of growth in the renewable energy industry.

3.2.3 Market Benefits

In addition to the more intuitive benefits cited above, the merit order effect is an additional benefit from renewable generation. The merit order effect describes the effect of renewable generation on the electricity market as it offsets more expensive generation thereby reducing the overall market price. The wholesale electricity market functions as an auction system whereby the available generators bid based on their willingness to generate and their own marginal costs. Generators with lower marginal costs or technical constraints preventing rapid changes in generation—nuclear power stations for example—tend to bid lower prices in order to ensure they will be able to participate in the market. Flexible generators with low capital costs and high marginal costs may place higher bids on the basis that they can achieve better returns by generating exclusively during periods of high market prices. Once the demand is determined, the market price is set at a level to meet demand. All generators then receive the same price and generators with bids higher than the market price do not generate during the period.

Renewable generation has a zero marginal cost and will always participate in the market. The presence of zero-cost generators serve to reduce the demand from other sources. As long as the supply curve has a positive slope, increased demand leads to higher market prices and the temporary reduction in demand leads to lower prices. The supply curve is effectively shifted along the merit order of generators. A report published by the Fraunhofer Institute

(Sensfuss, Ragwitz, & Genoese, 2007) looking at the magnitude of the effect in Germany in 2006 found a benefit in the range of €3 billion–€5 billion.

In the long run, reduced market prices may lead to a reduction in investments or new generation, increased mothballing of capacity and an increase in decommissioned plants. These factors reduce the magnitude of the merit order effect.

3.3 Energy Security Benefits

Energy security is another common target of renewable energy deployment subsidies: if the overall share of imported energy is reduced, or the diversity of sources increased, the country will become less sensitive to threats such as price volatility, political instability in energy-exporting countries, competition for limited resources, industrial action, market manipulation and the disruption of infrastructure due to adverse weather, natural disasters or terrorism.

The European Union specifically mentions the security of energy supply as an objective of its Renewable Energy Directive (European Commission, 2009). Since the first version in of the Renewable Energy Law (Government of Germany, 2000), Germany has also included explicit objectives of reducing the costs of energy supply to the national economy and avoiding conflicts over fossil-fuel resources. China's renewables policy sets the diversification of the energy mix as one of its primary objectives (National People's Congress, 2005).

As outlined by Ölz and Beerepoot (2010), wind power has energy security advantages and disadvantages. Primary among the former are that it relies on a freely available natural resource, so no fuel inputs are required. This means that power generation has a low cost and generating countries are not dependent on imports for their power generation. Wind generation is also widely distributed. This can minimize costs if it is located close to end-users; though it can also incur significant extra investment costs if grid connections are required from distant generation sites. Wind power's primary disadvantage is the variable nature of the resource: turbines cannot operate when wind speeds are too high or too low, with variability typically taking place on a timescale of minutes to hours.

Balancing variability is relatively easy when wind represents a low share of national power generation; it grows more challenging as shares increase. Chandler (2008) argues that variability requires sufficient power system flexibility, with important factors for managing variability including accurate forecasting, electricity trading that is close to real-time and flexible generation capacity. This might be wind turbines in distant geographic locations, other power technologies or stored energy from facilities such as pumped-storage stations. Tools for reducing demand can also be explored, such as incentives to reduce electricity consumption, contracting out interruptible load and the introduction of smart grid technologies. A study examining the extent of challenges from variability concluded that service challenges were far from insurmountable with sufficient investment in grid infrastructure and market pricing that reflects the value of flexibility (IEA, 2011b).

It is difficult to estimate the energy security benefits that have been achieved by wind deployment subsidies in Germany and China. A country's energy security situation is highly complex and assessments of security draw on many criteria that are often qualitative. Similarly, it is difficult to assign financial value to whatever benefits can be identified. Absent a full analysis of Germany and China's energy security dynamics, the most that can be said is that the proportion of electricity generated by wind in both countries suggests a positive effect on energy security. In Germany, this effect is not insignificant, with wind power generating 6.2 per cent of all electricity in 2010 (BMU, 2011a). It is more limited in China, where wind power generated 1.18 per cent of total generation in 2010 (State Electricity Regulatory Commission, 2011). The capacity installed under the country's concession tendering regime represented only 0.09 per cent of total generation. A fuller assessment of the value of this extra generation should take into account the steepness of the supply curve for alternative energy technologies.

Energy security impacts also need to be seen within the context of each country's larger ambitions for wind power. Germany aims to double the share of electricity generated by renewables, from 17 per cent in 2010 to 35 per cent in 2020. Wind power specifically is intended to meet 25 per cent of electricity generation by 2025, with onshore generation accounting for 10 per cent and offshore 15 per cent (BMU, 2010a). In its 12th Five-Year Plan (2011–2015), China foresees the construction of six onshore and two offshore large wind power farms, which would add 70 GW of capacity to the 42 GW installed by the end of 2010. According to the Global Wind Energy Council (2010b), objectives to increase national wind energy capacity to 90 GW by 2015 and 150 GW by 2020 are likely to be met. The IEA estimates that, with its current policies, China will have up to 151 GW of wind capacity by 2020, representing 8.5 per cent of total projected capacity (IEA, 2011d).

While recognizing the potential future benefits for energy security, it should also be recognized that these will incur extra costs—over and above the cost of the primary support mechanisms—related to balancing out the variability that comes with increasing wind power supply. From a review of different studies (Güll & Stenzel, 2005), the IEA estimates that total system integration costs for wind power are likely to be subject to significant variation between different countries. Costs in two scenarios considered by a 2002 study were estimated at between €5 and €15 per MW, though, given the many different dimensions related to integration costs (variability, uncertainty, transmission, adequacy, system rigidity etc.), they cannot be taken as general benchmarks (Strbac et al., 2002, as cited in Güll & Stenzel, 2005). There is disagreement over the extent to which such costs should be identified as subsidies to the industry, given the need for some grid investments to be made regardless of the expansion of the renewable energy industry and the various different mechanisms that might be used to pay for such investments.

3.4 Development of Wind Energy Technology

Reducing costs over time is essential for the wider deployment of renewable energy technologies and a key objective of support mechanisms—lower costs will allow for increased deployment at any given level of spending, with attendant impacts on the cost-effectiveness of any environmental, economic and energy security benefits. Eventually, sufficient cost reductions should allow renewable energy technologies to compete without the need for subsidies. Under certain favourable resource conditions, wind energy has already reached grid parity—it can generate electricity cheaply enough to compete with other power sources at the electricity market price.

Future technological cost reductions are often projected using "learning curves," which predict as a rough rule of thumb that costs fall at a constant rate with each doubling of cumulative production during a "linear learning" phase of a technology's development. It should be noted that learning curves themselves are an empirical observation and do not imply causality between deployment and cost reductions. The rationale behind deployment subsidies, however, is that costs will fall through "learning by doing"—actual roll-out will increase skills and help to identify and overcome various challenges in the production process. It is also anticipated that deployment subsidies will promote private research and development activities, since they create the market conditions that allow private investors to profit from developing more efficient technology. A limitation to the use of learning curves for predicting future costs is that, in practise, costs do not always continue to fall at a fixed rate. Ferioli, Schoots and van der Zwaan (2009) identify three stages of cost-development as production of a technology increases: first, a "linear learning" stage, where costs fall at a fixed rate as cumulative production doubles; then a "maturity" stage, where the rate of cost reductions to a doubling of cumulative production begins to fall; and finally "senescence," where costs level out entirely and do not change, regardless of doublings in cumulative production. The opposite scenario is also possible, where, despite net cumulative capacity remaining constant, learning may still take place.

Technological advances in onshore wind power have resulted in overall increased production efficiencies of around 2–3 per cent annually over the second half of the 1990s and the 2000s, amounting to a total cost reduction of almost 30 per cent (EWEA, 2009a). While cost reductions can still be anticipated, onshore wind is a relatively mature renewable energy technology. The IEA's wind technology roadmap reports that "no single element of onshore turbine design is likely to dramatically reduce cost of energy in the years ahead" (IEA, 2009, p. 19). However, it does estimate that onshore wind energy will exhibit a learning rate of 7 per cent up to 2050. Based on the IEA's deployment projections, this would see investment costs in 2010 falling 17 per cent by 2030 and 23 per cent by 2050. Potential areas for improvement are thought to include wind energy resource assessment, turbine technology and design (e.g., height), and supply chain issues (IEA, 2009).

There are significant challenges, however, to estimating the share of cost reductions that have been brought about by a single country. It is also difficult to parse out the impacts that can be attributed to deployment policy as opposed to other factors that influence learning. In a study of wind turbine development in the Netherlands and Denmark, Kamp, Smits and Andriesse (2004) argue that there are three additional factors to consider. The first of these is "learning by searching," which refers to R&D activities. Second, "learning by using" refers to knowledge that is acquired in the operation of technology. This includes issues such as identifying causes of stress on components, turbine efficiency and turbine failure, and might be considered a consequence of deployment, along with learning by doing. Finally, "learning by interacting" refers to contacts between users and producers—allowing producers to share learning with one another and to respond to the experience and needs of users in operating turbines.

Applying this more complex model to Germany and China highlights the difficulties of assigning specific cost reductions to deployment expenditure. In 2006, for example, Germany spent €16 million on R&D (WindFacts, 2010); private actors also invested in R&D, with REPower Systems and Nordex, two of its largest wind turbine producers, spending €11 million and €14 million respectively (European Wind Energy Technology Platform, 2008). It is not clear how cost reductions can be allocated between deployment subsidies and R&D spending, nor what proportion of private R&D spending is a result of deployment policies. Moreover, it is not clear to what extent national subsidization might have contributed to cost reductions that are global in nature.

The case of China is slightly different, as government policy has largely focused on deployment and the development of an efficient supply chain until very recently, with few mechanisms focused on R&D. According to the 2010 China Wind Power Outlook, this may have reduced costs in terms of manufacturing, but it has also resulted in Chinese firms struggling to compete in terms of quality (Hu, Shi, & Li, 2010). More important in China is likely to be the role of "learning by interacting": various policy mechanisms have been used to favour domestic companies and to encourage foreign firms to enter partnerships with domestic firms, to fertilize technology and knowledge transfer.

Given the difficulty of determining the cause of cost reductions and the uncertainty of future projections, this study considered it unfeasible to assess the extent to which deployment subsidies had incentivized technology development. Broadly, it seems clear that the costs of wind power are likely to be reduced in at least four main ways: "learning by searching" in research and development, "learning by making" in production, "learning by using" in operation and "learning by interacting." In addition, the experience of China indicates that "learning by interacting" may be particularly important for developing countries and for countries entering a market with established players.

3.5 Effectiveness Summary

To assess whether the subsidies have had their desired effects, each of the goals listed earlier is now presented alongside estimates of the actual outcomes of the policies (see Table 5). In each step—between objective and output, and output and outcome—it should be noted that in some cases causality is not always certain. For example, some share of deployment may have taken place without subsidies, such as windy areas where turbines can operate cost-effectively, or due to interactions between subsidies, such as in China where various industrial support measures complemented the concession tendering system.

TABLE 5. SUMMARY TABLE OF EFFECTIVENESS OBJECTIVES, OUTPUTS AND OUTCOMES

<table>
<tr><th>POLICY OBJECTIVES</th><th>OUTPUTS</th><th>INTENDED OUTCOMES</th><th>ESTIMATES OF ACTUAL OUTCOMES</th></tr>
<tr><td>Environmental goals:
• Mitigation of climate change
• Reduction of local pollution</td><td rowspan="4">Increased deployment of renewable energy (installed capacity):
Germany—an increase of 21.1 GW from 2000–2010, with a total generation over the period of 237 TWh.
China—an increase of 3.35 GW from 2003–2007 (concession tendering regime only), with a total generation over the period of 22.1 TWh.</td><td>Where renewable energy generation replaces generation by technologies with higher life-cycle emissions of CO_2 and other pollutants, such emissions will have been offset.</td><td>Carbon savings:[1]
Germany – 684.2 million tonnes
China – 53.8 million–114.3 million tonnes (concession tendering regime only)
No estimates developed for local pollution</td></tr>
<tr><td>Economic and social goals:
• Industry creation
• Job creation
• Regional development
• Increased energy access</td><td>Increasing deployment of renewable energy technologies can:
• Foster national industries, creating jobs in manufacturing, installation and maintenance, and allowing for the export of RETs and related services
• Allow for the export of renewable energy to countries that are not generating enough renewable energy to meet their own targets
By influencing the location of investments, this economic wealth can be targeted at the development of specific regions. In developing countries, energy access may be a particularly important benefit. Expanding electrification can contribute to achieving every Millennium Development Goal.</td><td>Total share of global manufacturing market represented by national companies:
Germany – 13% in 2010
China – 32% in 2010 (concession tendering regime only)
Total gross jobs in sector:
Germany – 665,000 in 2000–2010 (402,000 in national installations and 263,000 in exports); and an further 168,000 operations and maintenance jobs until the end of the capacity lifetime
China – 55,500 jobs in 2003–2007; and an additional 23,500 until the end of the capacity lifetime (concession tendering regime only)
Note: it was outside the means of study to estimate net job creation. These impacts are therefore likely to be biased upwards.</td></tr>
<tr><td>Energy security goals:
• Increased energy security</td><td>Increasing the share of renewable energy will increase the diversity of the energy supply mix, making a country less reliant on other sources of energy, notably imported fossil fuels.</td><td>Proportion of electricity from wind power:
Germany – 6.2% in 2010
China – 0.09% in 2010 (concession tendering regime only; total installed wind capacity in 2010 produced 1.18% of total generation)</td></tr>
<tr><td>Development of RETs:
• Cost reductions</td><td>According to “learning-by-doing” models, costs will be reduced by a fixed amount every time the installed capacity of a renewable energy technology doubles. Market support for RETs will also stimulate private investment in R&D. These cost reductions will, in turn, lead to increased deployment of RETs, contributing to all three of the outcomes listed above.</td><td>No appropriate indicators identified</td></tr>
</table>

[1] *China range dependent on fuel type being offset: and the lower end, gas, and at the higher end, coal.*

Overall, the indicators suggest that both subsidy programs have succeeded in achieving their desired output—increased deployment—and outcomes.

In comparing the two countries, it is clear that Germany's EEG has had much larger impacts than China's concession tendering regime simply because of the much larger amounts of installed capacity that it has stimulated. Further comparison between the two countries—such as relative success per unit of MW installed—is somewhat frustrated by the lack of data on China's other support schemes for renewable energy. Nonetheless, it is clear that mechanisms to support national industries appear to have played an important role in China's remarkably swift capture of an international market share in turbine manufacture.

Having established that both policies appear to have achieved some of their desired effects, it is necessary to ask if the policy can be considered cost-effective—were its objectives achieved at a "reasonable cost"?

4.0 Cost-Effectiveness

An assessment of the cost-effectiveness of these subsidies must first begin by estimating their costs. Then, two lenses of analysis can be applied. First, were the policies cost-effective in an "absolute" sense—in other words, would other policy tools be more effective at the same cost? Second, were the policies cost-effective in a "relative" sense—was one subsidy scheme designed in a way that made it more efficient than the other? Given the very different subsidy mechanisms in Germany and China, and the relatively poor information about any Chinese policy other than the concession tendering system, this study does not attempt to conduct a relative cost-effectiveness analysis.

4.1 Calculating Scheme Costs

In Germany, the total costs of the subsidies was estimated using data on subsidy tariffs, electricity generated and electricity capacity in wind power as reported by the BMU and the German Association of Network Operators (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit [BMU], 2011d; Verband der Netzbetreiber, n.d.). As wind generation fluctuates according to the site of the installation, the wind index reported by Bundesverband WindEnergie e.V. (2010) was used to determine the amount of generation that would be expected from installations installed in any given year, assuming an average wind resource. This was then used to estimate generation per cohort of installations in each year, given the actual wind resource, which was assumed to be average for all years after 2010.

The subsidy was defined as the difference between the payment made to wind power generators and the underlying power price. Determing the exact tariff being received by different wind turbines was complicated by the design of the EEG's support for wind: a two-step tariff system. The "initial tariff" is paid for at least the first five years after commissioning. After this point, the "basic tariff" may be paid instead. The exact point at which the basic tariff is paid depends upon the performance of a wind farm relative to a reference case, taking into account the characteristics of the turbine. The policy is designed to provide support that is sensitive to resource-intensity by giving less support to generators that perform well. As of 2005, a floor was placed on poor performance, requiring wind farms to generate at least 60 per cent of the reference yield (Government of Germany, 2000, 2004, 2008). This study was unable to identify any official information on the average point at which German wind farms move from the initial to the basic tariff. However, from official reports of the total disbursements to wind power under the EEG, it is possible to infer that the number of wind turbines receiving the basic tariff in 2010 must be negligible. Although installations in existence prior to 2000 also received support under the scheme, this was not included in the analysis for the sake of simplicity, with estimates of both costs and benefits in this study only based on the new capacity installed from the year 2000 onwards.

Estimates take into account changes made to the EEG in 2004 and 2008. Annual average wholesale power prices are based on the average Phelix day base prices, obtained at the European Energy Exchange (EEX). The power price in future years was taken to be the power price in 2010, corrected for inflation. It is assumed that average inflation across the lifetime of the policy was 2.0 per cent (Statistisches Bundesamt Deutschland, 2010).

In China, the concession tendering system was structured such that project developers won bids by proposing a tariff to be received for the first 30,000 full-load hours of wind power production. Eighteen tendering projects were placed for bids in seven different provinces between 2003 and 2007 (Hu, Shi, & Li, 2010). Subsidy costs were estimated by taking the difference between these tariffs and the power price for the average full-load hours generated per year by each wind farm, assuming 30,000 full-load hours to be equal to 3,000 GWh of generation for a 100 MW installation. Average full-load hours for different regions in China were estimated as being equal to those reported for 2007 (Shi, 2008). Power prices are difficult to identify in China and were ultimately identified through personal communication with Chinese Wind Energy Association expert Shi Pengfei. It was assumed that each wind farm took two years to enter into operation following successful bidding, such that the start date of payments was in 2005. Wind farms were estimated to have a lifetime of 20 years. As inflation fluctuated significantly between 2003 and 2010, average annual inflation was taken into account until 2010. For future years, a 2 per cent inflation rate was assumed, this having been the average rate between 2003 and 2010.

TABLE 6. KEY INDICATORS ON THE FINANCIAL COST OF WIND DEPLOYMENT SUBSIDIES (DISCOUNTED VALUES)

	GERMANY	CHINA
Total subsidy in 2000–2010/2003–2010 (€ billion)	13.2	0.33
Total subsidy commitment over policy lifetime (€ billion)	30.7	0.94
Average spending per year (€ billion, based on 20 year life))	1.0	0.047
Total TWh of electricity generated	929.6	129.0
Average subsidy per kWh (€/kWh)	0.033	0.007

Notes: Estimates for both countries are stated in 2010 Euros, assuming a CNY/EUR exchange rate of 0.1113.

The most striking feature of these estimates is the low cost per kWh of generation in China compared to Germany. To a large extent, this might be accounted for by China's subsidy mechanism. In theory, tendering is argued to be an effective price-setting mechanism, as developers are incentivized to bid the lowest price at which they can cover their costs. In some countries, however, tendering has resulted in companies underbidding in order to win a contract and subsequently struggling to realize promised investments. Although all the contracted projects in China appear to have been completed and generating, Li et al. (2007) report that the tendering system did indeed result in "ultra-low" bidding prices. This was apparently a strategy of large state-owned energy groups who purposely agreed to build projects at a loss in order to enter a sector they believed to have good future prospects. Furthermore, companies are reported to have actively planned projects of a size that would be too low to qualify for inclusion in the tendering system, in order to be granted tariffs under the more generous "governmental approval" system (CITIC Securites, 2008; Recknagel, 2010).

The impact of this low bidding can be estimated by calculating what the subsidy cost would have been if the capacity had guaranteed the rates introduced by China's 2009 feed-in tariff. Assuming that no portion of the low bidding was due to particularly intense wind resources on the sites in question, this would imply that the support required to deploy 3,350 MW of capacity in China would be a total commitment of €2.73 billion and a subsidy per kWh of €0.021. This is in the same order of magnitude as the costs of the German scheme. Even taking into account this information, it is still not possible to determine which country offered most support without a full accounting of other financial incentives, which may be significant in China in particular. For example, the CDM and favourable taxation have also been used to support the development of wind power, and their inclusion in this cost accounting might significantly alter estimates. As such data is hard to identify and a more in-depth analysis is outside of the scope of this study, it is emphasized that the estimates presented here should be viewed as headline indicators only, suggesting the general scale of support to the wind sector. They are certainly conservative.

4.2 Absolute Cost-Effectiveness

Studies looking at the cost-effectiveness of renewable energy technologies have often focused on one particular outcome. This can result in the entire cost of the policy being compared to the value of a single benefit. The approach taken by this analysis is to estimate a financial value for as many of the outputs as possible and to compare this to the absolute cost of the scheme. Estimates were made for the financial value of carbon emissions offset and gross jobs created in each country. The financial benefit of carbon savings was estimated, as reported earlier, according to a minimum and maximum carbon value of €15 and €200, respectively. The financial benefit of an average job in the wind industry was estimated according to assumed minimum and maximum wage values, derived from reported average wages in the electricity sector in Germany and the wind sector in China: €30,000–€50,000 per job and €3,005–€11,130 per job, respectively (World Salaries, 2008; Institute for Labour Studies, Ministry of Human Resources and Social Security, 2010).

A comparison of costs and benefits is shown below: first, in Figure 2, from the start of the subsidy scheme to the latest year of available data; and second, in Figure 3, projected across the lifetime over which installed capacity will receive subsidy payments under each scheme. In China, it is assumed that tendered wind projects took an average of two years to come online, such that the bidding round completed in 2003 first resulted in measurable costs and benefits in the year 2005.

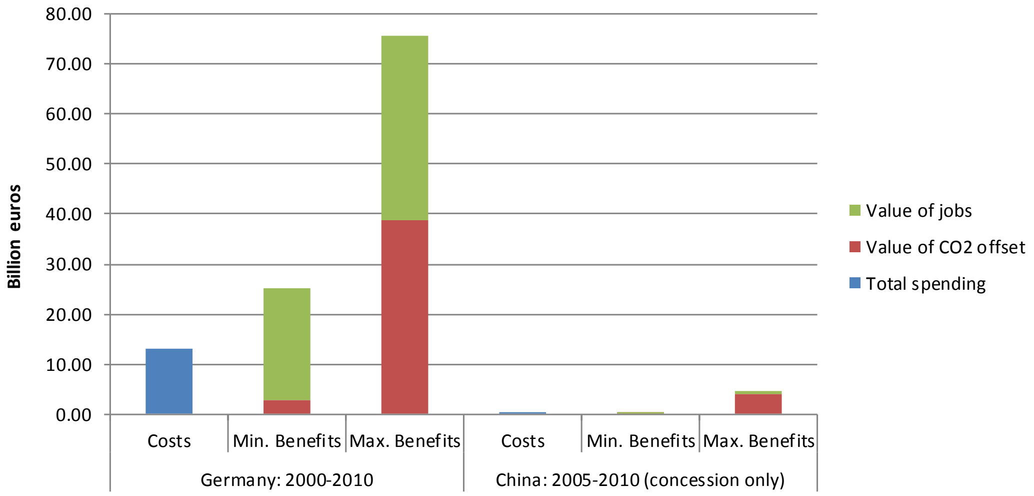

FIGURE 2. ESTIMATES OF COSTS AND BENEFITS OF GERMAN AND CHINESE WIND POWER TO 2010

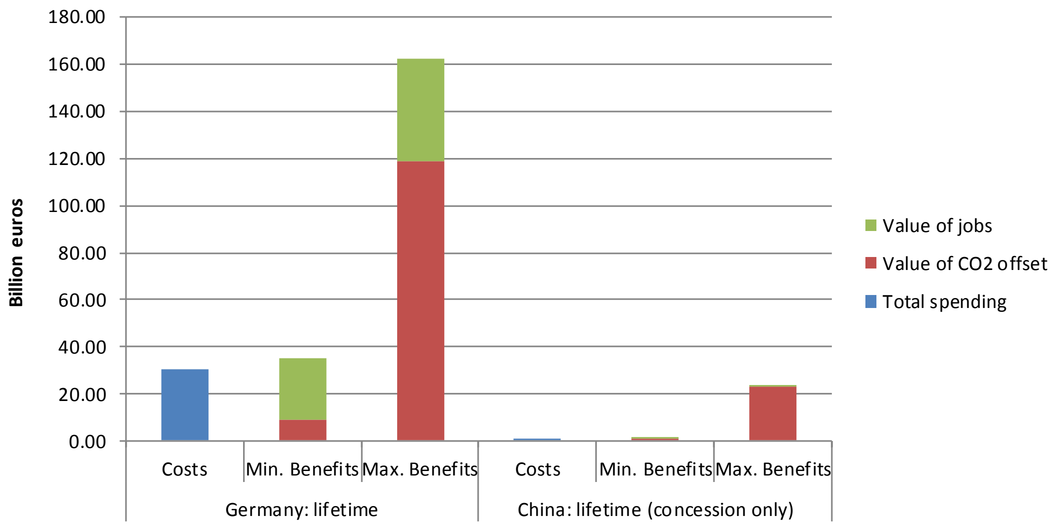

FIGURE 3. ESTIMATES OF COSTS AND BENEFITS OF GERMAN AND CHINESE WIND POWER ACROSS THE POLICY LIFETIME OF INSTALLED CAPACITY

The analysis indicates positive results, suggesting that subsidies to wind power in both countries are likely to qualify as "cost-effective" under relatively conservative assumptions about the impacts on carbon dioxide and jobs, and the associated value of those impacts. It should be stressed, however, that this analysis is highly limited, having employed simplistic estimation methods as an initial exploration of these questions. Fuller accounting of costs and benefits would be required to draw any conclusive findings, especially given qualitative information about benefits that is not captured in this numerical analysis, as outlined below.

Of the two benefits estimated in figures 1 and 2, carbon savings has the greatest potential to influence whether or not the subsidies might be judged cost-effective. This is largely due to the significant uncertainty around an appropriate price for carbon. For the period 2000–2010 in Germany, the "break-even" price for carbon—the price at which the subsidies could be fully justified by carbon savings alone—is equal to around €75. For the period 2005–2010 in China, it is equal to around €17–€36, although it is likely that the true cost of reduction has been masked by underbidding in the tendering system. Were the same capacity to have been installed using the tariffs established in 2009, it would have implied a break-even price of around €39–€83.

Jobs represent a more important benefit in Germany than in China, partly because the valuation method is based on the average wage in each country and partly because of the higher levels of installation in Germany. In Germany, the expenditure of €30.1 billion is estimated to have created around 830,000 job years, giving a cost per job of around €36,000 per job year. In China, expenditure of €0.94 billion is estimated to have created around 80,000 job years, giving a cost of around €12,000 per job year. Caution should be exercised in interpreting these figures, however, as estimating the value of job creation through the average wage paid to each employee is a very rough measure, intended to estimate only the general magnitude of benefits. Separately, it should also be noted that the economic benefits estimated in this are likely to be overly optimistic, as they do not take into account net impacts—which would include negative economic effects implied by opportunity costs. This could greatly alter cost-effectiveness with respect to economic impacts, as implied by modelling that has estimated only modest job gains and even the potential for net job losses by 2020 in some European countries (Ragwitz et al., 2009).

Finally, three elements are also missing from the graphs above—namely, benefits related to energy security, the merit order effect and technological development. It has not been possible to estimate a financial value for these policy goals, though both would be expected to contribute a net benefit. The fact that wind power represents a modest percentage of electricity in Germany suggests that the value of energy security improvements is not insignificant, and it may become greater with time and within the wider context of other renewable energy deployment. The potential benefits related to technological development are uncertain; it can only be said that most cost reductions are still anticipated for wind power, but that no satisfactory method exists for estimating the extent to which individual support mechanisms might be associated with the causation of such gains.

5.0 Conclusions

This study estimates that Germany and China have committed significant subsidies to stimulate the deployment of onshore wind power. In Germany, capacity installed between 2000 and 2010 commits the country to spending an estimated €30.7 billion. In China, capacity installed under the 2003–2007 concession tendering scheme will commit estimated expenditures of €0.94 billion.

In attempting to conduct an exploratory cost-effectiveness analysis, this study yields more methodological findings than it does concrete conclusions. The first and foremost of these is that any such analysis, if pursued earnestly, is extremely difficult to do in a robust and comprehensive manner. Accounting for the full range of subsidy mechanisms in support of a policy is highly resource-intensive, particularly posing challenges in countries where transparency is low and a wide range of subsidy mechanisms are offered. Estimating and evaluating benefits is also a challenge: the cost-effectiveness of GHG impacts is significantly influenced by assumptions about the value of offsetting carbon; economic benefits may be greatly overestimated unless they are based on an analysis of net impacts; and both energy security benefits and technology development benefits are difficult to evaluate at all.

Nonetheless, the limited analysis conducted in this study suggests that, even under conservative sensitivities, wind power subsidies in Germany and China may achieve benefits that balance their costs. This is dependent on the assumption that no other deployment policies would significantly increase costs beyond those estimated here. It is possible that an assessment of net job creation—as opposed to gross job creation—might alter this picture. The inclusion of energy security and technology development benefits, however, would be likely to increase the argument for cost-effectiveness.

Going forward, it is clear that if countries are committed to subsidizing the deployment of renewable energy, further analysis of cost-effectiveness could—and should—usefully shed light on how these policies can better make use of scarce fiscal resources. Developing more precise methods for the analysis of cost-effectiveness could be a useful step in this direction.

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