Is Germany's Energy Transition a case of successful Green Industrial Policy? Contrasting wind and solar PV

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Abstract:

In this paper, we address the challenge of Germany's energy transition (*Energiewende*) as the centrepiece of the country's green industrial policy. In addition to contributing to global climate change objectives, the *Energiewende* is intended to create a leading position for German industry in renewable energy technologies, boost innovative capabilities and create employment opportunities in future growth markets at the least possible cost. The success in reaching these aims, and indeed the future of the entire concept, is hotly debated.

The paper aims to provide an up-to-date assessment of what has become a fierce controversy by comparing solar photovoltaic (PV) and wind energy along five policy objectives: 1) competitiveness, 2) innovation, 3) job creation, 4) climate change mitigation, and 5) cost. We find mixed evidence that Germany reaches its green industrial policy aims at reasonable costs. Wind energy seems to perform better against all policy objectives, while the solar PV sector has come under intense pressure from international competition. However, this is only a snapshot of current performance, and the long term and systemic perspective required for the energy sector transformation suggests a need for a balanced mix of a variety of clean energy sources.

Keywords: Green industrial policy; renewable energies; Germany

1. Introduction

Green industrial policy, that is, government intervention to hasten the restructuring of the economy towards environmental sustainability (Pegels, 2014), is a particularly suitable instrument to achieve the radical and long-term transition required to maintain acceptable living conditions for ourselves and our descendants. Governments must intervene, because market mechanisms such as prices alone are failing to bring about the drastic and fast changes to the very fabric of our economies required for the protection of our planet (Hallegatte et al., 2013). Linking environmental protection to such traditional aims of industrial policy as competitiveness, job creation and innovation as 'co-benefits' may help it to win supporters. Environmental sustainability on its own has failed to become a driver of structural change in most countries.

However, the multiplicity of aims also renders green industrial policy making and the assessment of policy success more complex. This paper analyses one of the most far-reaching attempts globally to initiate a policy-driven transformation of an entire economy through green industrial policy: the German '*Energiewende*'. We compare wind and solar PV electricity promotion along five central green industrial policy aims: fostering competitiveness, inducing innovation, creating jobs, mitigating climate change and minimising cost to consumers.

These policy aims are not always in harmony, and even when they are, vested interests may prevent the required shift from polluting to clean economic activities. The energy sector is a prime example for these challenges. Energy literally powers economic development. Hence, energy policy must be considered as a cornerstone of any industrial policy, regardless of the latter's specific objectives, approach and implementation. Through its impact on energy availability in general, and through more specific measures targeting the promotion of different energy sources and their relative prices, energy policy has a strong influence on an economy's competitiveness, employment, sectoral diversification patterns, trade position and long-term technological trajectory.

As a result, energy policy is invariably designed and applied within a veritable minefield of stakeholders, interests, conflicts and alliances. It requires a long-term planning perspective and a holistic look at political, social, economic and technological challenges and scenarios. Above all, energy policy fundamentally determines a country's future basic infrastructure for decades ahead and thus creates strong lock-in effects and path dependency (Lecocq & Shalizi, 2014, Unruh, 2000). It is a field of economic policy that does not lend itself to frequent shifts and reorientations unless huge investments are to be turned into stranded and wasted assets (Rozenberg et al., 2014).

The above applies in particular in the context of the German case. The country is amidst a fundamental energy transition *(Energiewende*), which involves a complete phase-out of nuclear energy and a deliberate policy of reliance on renewable energy sources. This necessitates a basic consensus on societal preferences, resulting energy policy aims and the way ahead. In a somewhat stylized perspective, German society has generally been characterized by a strong technological risk aversion; more specifically, the nuclear exit policy commands broad political and popular support and such technological options as carbon capture and storage or hydraulic fracturing meet with strong public opposition. Also, climate change considerations figure high on the agenda of societal concerns. The issue of energy prices currently somewhat dominates the debate around energy policy, both for industrial and household consumption, and this has become one of the essential yardsticks for assessing the progress and prospects of the ongoing energy transition towards renewables.

The swift transition to various renewable energy sources primarily for electricity generation (but also increasingly for heat generation and fuels) constitutes the centrepiece of German energy policy. For the purpose of this paper, an exclusive focus on electricity generation is adopted. Based on own calculations and a review of existing literature, the paper aims to provide an up-to-date assessment of what has become a fierce controversy. We compare solar photovoltaic (PV) and wind energy along five dimensions: 1) competitiveness, 2) innovation, 3) job creation, 4) climate change mitigation, and 5) cost.

These aims are derived from policy statements on the objectives of the energy transition presented in Section 2, along with the methods used to assess the costs and benefits of the policy measures applied. This assessment is a complex undertaking fraught with diverse methodological challenges. Political positions and lobbying often guide seemingly technical calculations. An attempt is thus made to rely to the extent possible on quantitative assessments and clearly spell out the underlying assumptions. We use revealed competitive advantages as indicators for competitiveness, relative patent shares for innovation, gross number of jobs for job creation, and tons of CO_2 avoided for climate change mitigation. We contrast those with the differential cost of the feed in tariffs for wind and solar PV, respectively. Section 3 presents and discusses the results of the assessment for both technologies separately and in direct comparison. We find that wind energy performs better in all dimensions, but argue in the concluding Section 4 that this does not result in the imperative to concentrate exclusively on wind energy support. The assessment at hand is a snapshot of current performance, while the necessary systemic and long-term perspective for transforming the energy sector suggests the need for a balanced mix of a variety of clean energy sources.

2. Methods

2.1. The German Energy Transition: Objectives and Measures

A national priority project of the highest order, such as the energy transition, is invariably governed by a complex set of objectives. To some extent, these have been officially pronounced and codified in legal documents. In addition, they can be derived from ministerial policy statements and publications.

With the Renewable Energy Sources Act (EEG) being the most important green energy policy law, its expressed policy objectives deserve prime consideration (Renewable Energy Sources Act – EEG 2012). In its Article 1 on the purpose of the law, the following objectives are listed:

- “Sustainable development of energy supply.”
- “Protecting our climate and the environment.”
- “Reducing the costs of energy supply to the national economy.”
- “Further development of technologies for the generation of electricity from renewable energy sources.”

In various publications, statements and speeches by the relevant Government entities (Ministry of Environment, Nature and Nuclear Safety; Ministry of the Economy and Technology, as well as the Chancellor herself), the energy transition is portrayed as contributing to:

- Strengthening Germany's leading global market position for climate-friendly technologies.
- Ensuring reliable and affordable energy supply to maintain competitiveness.
- Boosting innovative capabilities of industry.
- Creating employment opportunities from renewable energy development.
- Mitigating climate change.
- Saving scarce resources and reducing import dependency from fossil fuels.

In general, renewable electricity promotion policies in Germany are built around the concept of feed-in tariffs (FiT), whose core elements were established as part of the EEG in 2000. They are complemented by dedicated renewables loan programmes, as well as various types of support to research and development activities (R&D) (direct funding, demonstration projects, innovation alliances etc.) as part of science and innovation policies. Neither local content policies nor government procurement or renewables purchase obligations (outside the EEG-FiT, which constitutes a de facto unlimited purchasing commitment) are in place at either the federal or the state level. The German renewables policy scenario can thus best be characterized as being a combination of a robust legal and policy framework, sustained funding of a diversified set of research institutions and an emphasis on price-based rather than quota-based investment incentives.

Presently (early 2014), a fierce debate is raging in Germany on the impact and further adjustment needs of the EEG (see, for example, Diekmann et al., 2012a, EFI, 2014, Fraunhofer ISI, 2014). One trigger is the massive and unanticipated expansion of solar PV installations under EEG provisions. With PV panel prices down by more than 60 per cent over the last six years, the expansion of capacity has exceeded government targets by a factor of two. Against this backdrop, political negotiations are ongoing in the new coalition government on a proposal to rein in future capacity expansion. Specifically, the proposal envisages the introduction of ceilings for future capacity growth, strong reductions of future FiT rates and an ambitious degression scale. In the following sections, we aim to contribute to a rational basis for decision making on the future of the German EEG, and the system of FiTs in particular, by contrasting cost estimates with quantitative indicators for benefits of solar PV and wind energy support.

2.2. Methodological approach

2.2.1. Cost assessment

The German feed-in tariff (FiT) approach has become an "export success story" in itself, and, to date, has been replicated in essence (with variations in detail) in more than 50 countries worldwide. It continues to be widely recognized as a benchmark for effective policy design in support of renewable energy expansion. Therefore—and also in view of limited annualized data availability for the volume and terms of renewable energy loans, as well as R&D expenditures—this paper will focus entirely on seeking to assess the cost-effectiveness of this policy instrument.

To this aim, we present estimates on the differential cost of the FiT, that is, the difference between FiT rates and the electricity market price. It is important to note that this estimate includes distributional effects, and is thus higher than the macroeconomic cost of wind and solar PV energy production induced by the FiT. This differentiation is essential, although not always made explicit in the literature. The additional macroeconomic costs themselves arise from the fact that electricity production from most renewable sources is still more expensive than from conventional sources. These costs can be measured as the difference between the levelized cost of electricity (LCoE) generated from renewable sources and the LCoE of non-renewable sources.[1] If a FiT is to induce investments in renewable energy, it needs to cover these costs and a reasonable markup as compensation for the added risks of such investments (for example, resource and technology risks, or social acceptance risks, see Waissbein et al., 2013). The markup, however, does not add to macroeconomic costs. It is rather a redistribution of funds from electricity consumers to producers of renewable energy. In the case of Germany, this is reinforced by the exemptions granted to energy intensive enterprises, which raise the burden on the remaining consumer groups. Since the burden on consumers features prominently in the public debate, we chose to use the differential costs, including the distributive markup component, instead of actual macroeconomic costs as an indicator for the cost dimension.

The shares of the FiT-related differential costs attributable to wind and solar PV are calculated based on the average annual FiT paid (in €ct/kWh) between 2005 and 2013. For each energy source and the volume of electricity fed into the grid, the total amount of paid-out FiT is calculated and compared with the prevailing electricity market prices, thus arriving at the differential costs (BDEW, 2013)[2].

2.2.2. Benefits assessment

After assessing the cost, we proceed to identifying the positive impact of support policies. What have been the benefits generated in terms of building up new competitive industries, fostering innovation, creating employment, and contributing to fighting climate change? Only after having assessed both the costs and benefits of policy interventions in favour of renewables will it be possible to meaningfully assess the question of cost-effectiveness.

We rely on two indicators to assess the development of Germany's competitiveness in wind and solar PV: world market share, defined as the share a country has in world exports for a given product, and revealed competitive advantage (RCA)[3]. The RCA is one of the most commonly used competitiveness indicators. It compares the export-import ratio of one product to that of all products for the same country. The values of RCA can vary hugely and theoretically reach infinity. In order to

[1] Levelized Cost of Electricity (LCoE) is calculated on the basis of the total expenses (investment, operation, maintenance, replacement, insurance etc.) of a project over its entire life span. These are discounted to the same reference point and divided by the present values of the electricity output. For a critique of various concepts of LCOE and grid parity see Bazilian, et al, 2013.

[2] While the average electricity price per household rose from 19 to 29 ct/kWh between 2005-2013, the FiT for onshore wind remained constant at about 9 ct/kWh whereas the FiT for solar PV fell from 53 to about 30 ct/kWh.

[3] Following Eichhammer & Walz (2009), our calculation of the RCA differs from Balassa's (1965) original concept, which is solely based on export performance.

be able to present the values better in graphs, we use the ln (logarithmic) function, "normalize" the values using the *tanh* function (tangens hyperbolicus), and multiply by 100: tanh(ln(RCA))*100 (see also Eichhammer & Walz, 2009, with data coverage up to 2008). In this approach, positive numbers indicate a competitive advantage.

In terms of data sources, we rely on the United Nations Commodity Trade Statistics Database (UNCOMTRADE, 2013).[4] The product nomenclature used originates from the Harmonized System (HS 1996), which is available at the 6-digit level. Specifically, for wind energy and solar PV, it offers the following two product groups:

- 850231: "Other generating sets—wind powered" (referred to below as wind converters).
- 854140: "Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels; light emitting diodes" (referred to below as solar PV).

Two caveats are in order:

First, it needs to be understood that the RCA approach of measuring competitiveness cannot discriminate between specialization patterns rooted in structural economic determinants (factor endowments, productivity etc.) and those caused by trade policy interventions. For instance, a country's temporary recourse to import restrictions or export dumping practices would translate immediately into an improved RCA value. Second, in a few cases annual fluctuations of country-specific export and import data are of such an immense magnitude that doubts arise as to their accuracy. However, UNCOMTRADE data cannot be verified here and must be assumed as being correct.

The measurement of innovation dynamics is notoriously difficult. In the absence of sufficient company-level data on R&D investments, international patent data can be a useful proxy indicator. However, evidence needs to be treated with care. Results will differ in accordance with the database applied, the country in which a patent has been filed, the reliance on either patent applications or patents granted as well as the inventor's or applicant's home country. Also, the significant time required for processing a patent registration and the incidence of cross-sectoral patent use (e.g., electronics patents applied in solar PV; machinery and automotive patents applied for wind turbine gearboxes) would ideally need to be considered. Lastly, patents can only indicate those aspects of the innovation process which are based on patented knowledge (Fraunhofer ISI, 2014). They thus provide only part of the picture.

The results presented in Figures 7 and 8 are based on the OECD Patent Database (as updated in January 2013 with data up to 2010, OECD, 2013). They cover patent applications (not patents granted), which are generally considered to be a better indicator for innovation dynamics. The relative patent shares (RPS) have been calculated by using the same methodology as applied earlier for calculating revealed competitive advantages. RPS thus compares, for a given country, the world share for a patent of one specific technology with the world patent share across all technologies.

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[4] Available at: http://comtrade.un.org

The solar and wind technology sectors have grown into significant providers of employment in the German economy. While no data are available on the number of net jobs created, there are reliable data on gross employment creation both directly through capacity investment and indirectly through maintenance, operation and other support activities.

To assess the environmental benefits of the FiT, we rely on directly avoided carbon dioxide (CO_2) emissions for which consistent time series data are available. Data in Table 3 are based on applying specific substitution factors for wind energy and solar PV, respectively. This is relevant in view of the fact that the emission intensities of coal, lignite and natural gas differ substantially. More specifically, the following substitution patterns are assumed:

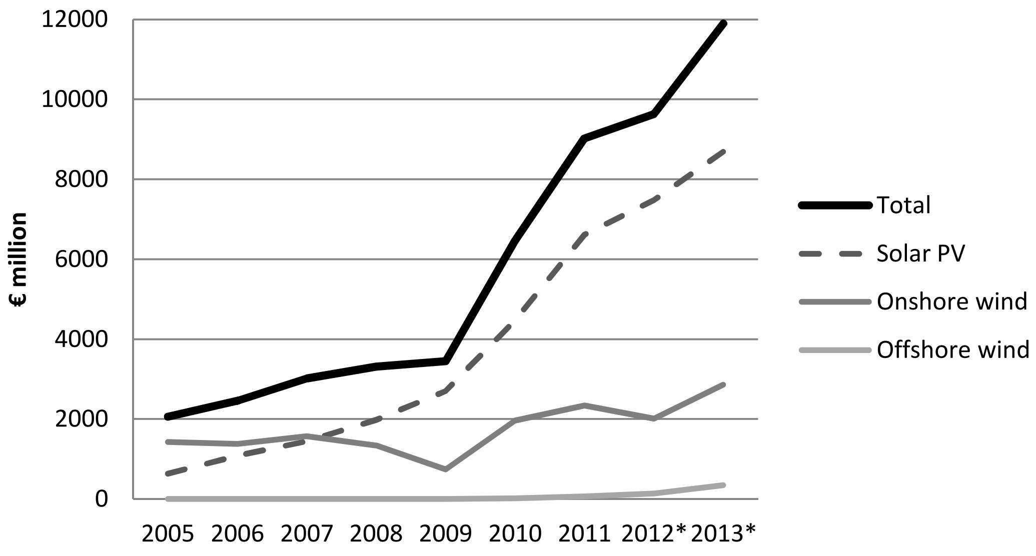
- For wind energy: coal 80 per cent, natural gas 17 per cent and lignite 3 per cent,
- For solar PV: coal 75 per cent, natural gas 22 per cent and lignite 3 per cent.

3. Costs and benefits

3.1. Costing the Feed-in tariff

Figures 1 and 2 present the shares of the FiT-related differential costs attributable to wind and solar PV, respectively.

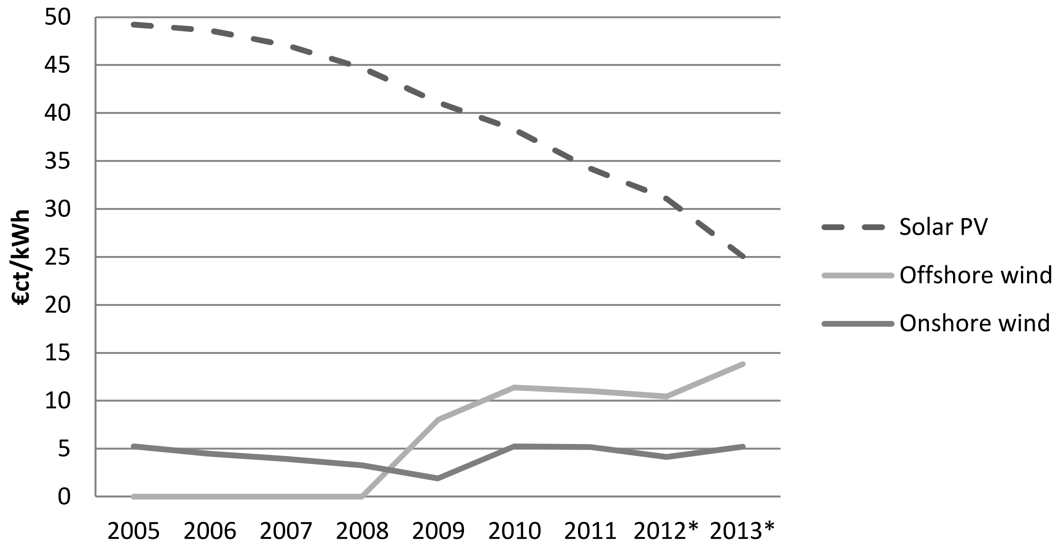
Figure 1 Annual differential costs in million € under EEG-FiT (2005–2013) [5]



*Projection
Source: Data from BDEW, 2013, pp. 37-38.

[5] Unless explicitly stated otherwise, all tables and figures refer to the case of Germany.

Figure 2 Annual differential costs in €ct/kWh under EEG-FiT (2005–2013)



*Projection
Source: Data from BDEW, 2013, pp. 37-38.

From Figure 1, it can be seen that the combined projected differential costs for wind energy and solar PV promotion amount to close to €12 billion in 2013—almost double the amount of 2010. Moreover, Figure 1 clearly shows a pattern of a relative increase in the weight of solar PV: between 2005 and 2013, the ratio of total solar PV subsidies to total onshore wind subsidies (in € million) rose from 0.4 to 3.0, i.e., from less than half to three times as much. This coincided with a narrowing of the same ratio in terms of €ct/kWh, as shown in Figure 2: in 2005, the average feed-in differential tariff for solar PV was 9.4 times higher than for onshore wind; in 2013 this factor was down to 4.8—the obvious explanation being the FiT reductions triggered by the phenomenal cost decreases and subsequent growth of solar PV electricity generation. While the latter grew by a factor of 27, wind-generated electricity just doubled in volume from 2005 to 2013.

However, a holistic look at the composition of electricity prices is necessary with a view to putting the EEG-surcharge in perspective. Electricity prices basically result from the costs of generation, transmission and distribution; various state taxes and levies; and finally the EEG-surcharge. In 2013, the latter accounted for 22 per cent of electricity prices for households and 35 per cent for industrial consumers. In 2005, the shares were 5 per cent and 7 per cent, respectively. Thus, while contributing between one fifth and one third to total prices, the EEG surcharge has increased rapidly in recent years to become a pronounced cost factor.

In the context of this growing relative weight, the distributional impact of the EEG-surcharge has become a controversial subject. In 2013, the EEG apportionment for electricity consumers, i.e., the rise in their electricity price attributable to the FiT, amounted to 5.3 €ct/kWh. Private households (with an electricity consumption share of roughly one quarter) have to bear 35 per cent of the surcharge while the industrial sector (with a consumption share of almost 50 percent) accounts for only 30 percent of the surcharge—largely a result of exemptions for energy-intensive industries. However, the financial burden to be borne by households is easily overestimated. A recent study concludes that in a scenario of a further 1.3 €ct/kWh increase of the electricity surcharge by 2015, additional expenditures would amount to just 0.1 per cent of the average disposable household income, although with a slightly regressive effect (Lehr & Drosdowski, 2013).

Furthermore, the total subsidy costs of the FiT are not higher than the subsidies paid for electricity generated from coal and nuclear power. In a recent study, Forum ökologisch-soziale Marktwirtschaft (2012) estimates a subsidy for fossil and nuclear energy of 10.2 €ct/kWh in 2012, amounting to a total subsidy sum of €40.3 billion. In essence, a visibility bias is at work here. While the subsidies for renewables appear explicitly as electricity surcharge on the power bill of end consumers, subsidies for conventional energy sources are embedded in state budgets. This applies not only to direct subsidies and tax incentives, but more importantly, to external costs such as environmental damage, the costly search and management process of nuclear waste disposal sites, and the risk of nuclear incidents.

3.2. Assessing the benefits of the energy transition

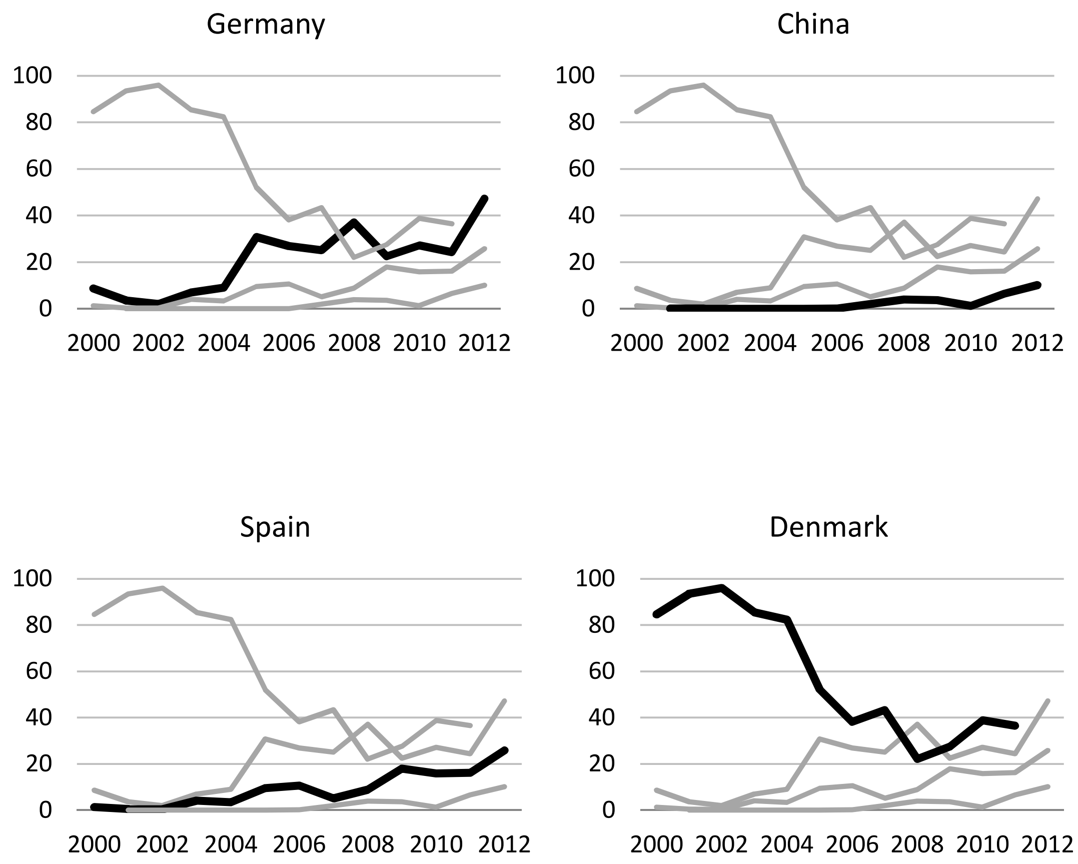
3.2.1. Competitiveness

The notion of competitiveness is one of the most fundamental concepts in economics. However, exactly how to define and measure competitiveness and how to delineate its meaningful remit has remained highly controversial, in particular when moving up from competing firms to competing locations, sectors or entire economies and, for that matter, nations. Famously, Krugman (1994) went as far as branding competitiveness as a “dangerous obsession” of policy-makers. This may indeed apply to much of the popular debate and its oversimplifications, yet it does remain a valid concern—economically and politically—to ascertain how goods produced in a country can stand the test of international market acceptance and how they fare in relation to the same goods produced elsewhere. This section therefore reviews the competitiveness of the German wind energy and solar PV industries.

Wind converter competitiveness

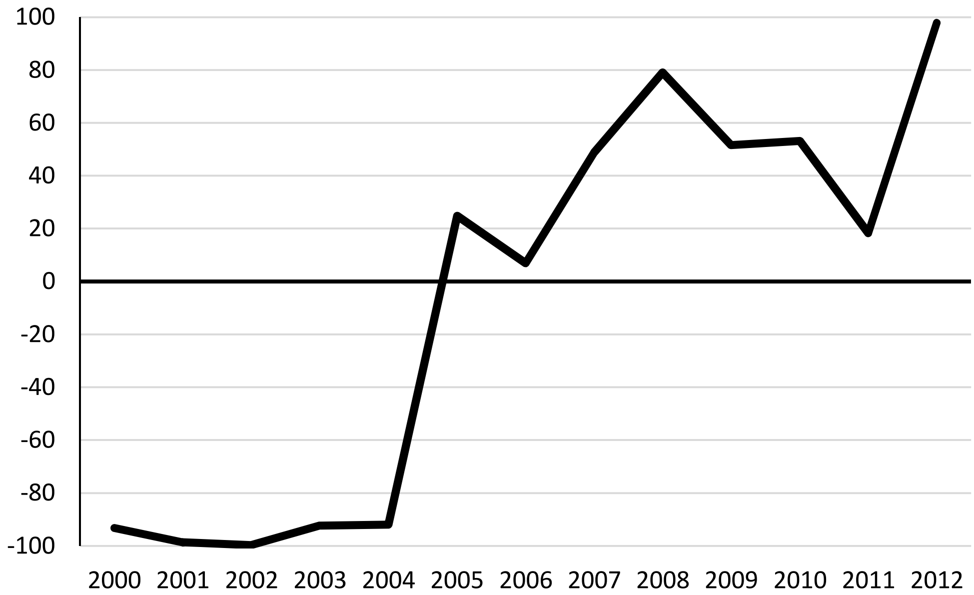
Figures 3 and 4 send the resounding message of the build-up over time of a highly competitive German wind converter industry. Between 2004 and 2012, its export share in the global market surged from 10 to almost 50 per cent - thus assuming the position of leading export country. The low world market shares before 2005 are explained by the fact that in those years Germany represented a lead market for wind energy – accounting for 45 per cent of wind converter installations worldwide in 2002 (down to 7 per cent in 2005). The pioneering FiT introduction had created such a strong domestic market pull that early export efforts were effectively stifled. A similar pattern can be observed for the revealed competitive advantage: its values increased sharply in 2005 and kept growing in the period up to 2012. In terms of comparator countries, the recent growth in China’s and Spain’s market shares is to be noted, as is the rapid and consistent loss of market shares by Denmark.

Figure 3 Wind converters: world market shares (percentage) by country 2000–2012



Source: Authors' calculations based on UNCOMTRADE.
Note: The four diagrams are identical, differing only in the country highlighted.

Figure 4 Wind converters: Germany's Revealed Competitive Advantage 2000–2012



Source: Authors' calculations based on UNCOMTRADE.

Beyond the aggregate data presented in the charts, industry analysts underline the particularly strong competitive position of German companies when it comes to offshore turbines (and offshore wind parks in general), as well as large-scale onshore turbines above 5 MW capacity. A particular driver of competitive strength originates from a classical technology cluster constellation in the four Northern states of Lower Saxony, Schleswig-Holstein, Bremen and Hamburg.[6] This so-called North Western Region Wind Power Cluster has grown into a densely interconnected web of more than 300 partners—comprising globally leading turbine manufacturers, specialized component suppliers, wind park operators, local governments and cutting-edge research institutions. The cluster boasts some of the industry's major innovations (e.g., the development of the 5 MW offshore turbine and the offshore test site Alpha Ventus).

At the same time, the wind cluster also owes some of its success to the long-standing track record of Germany's engineering, machinery and power sectors in general. Without the foundation of highly advanced manufacturing capabilities and skills across a whole range of industries, the German wind energy sector would not have been able to achieve global technological leadership.

Solar PV competitiveness

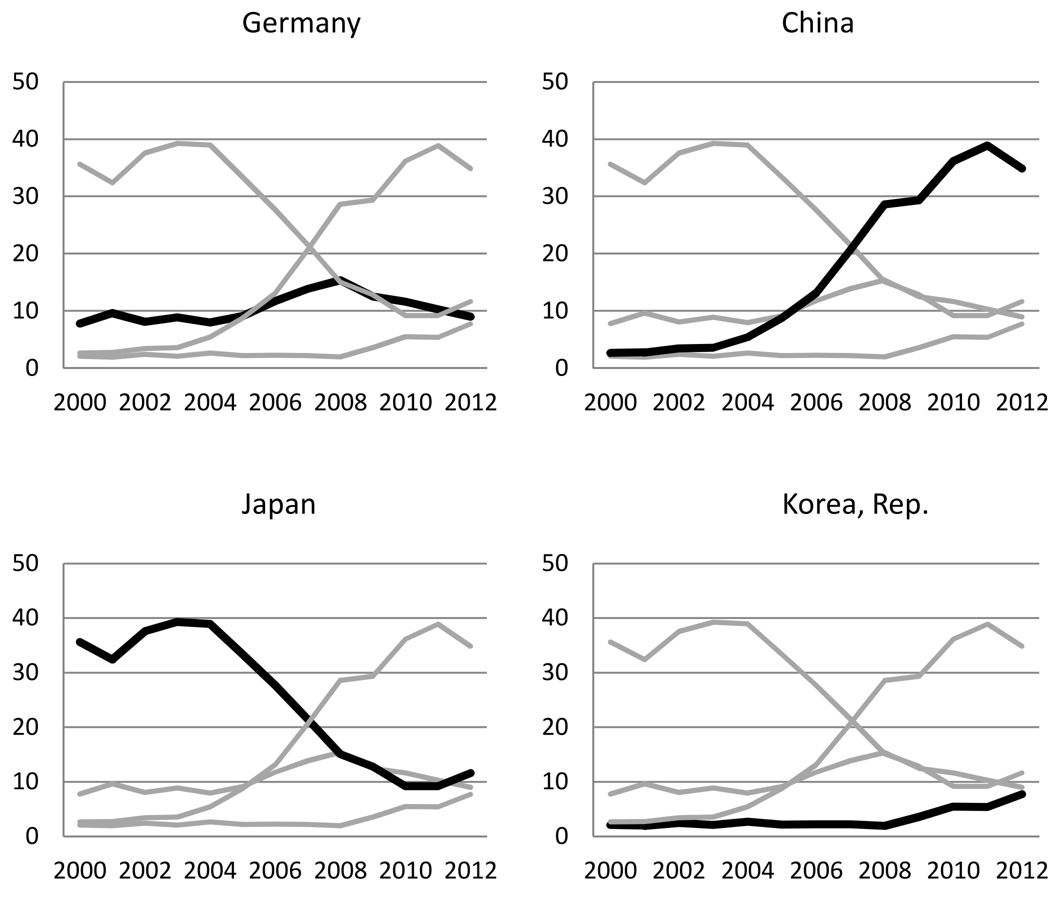
The global solar PV market, even more so than other renewable energy markets, is a highly political market shaped by trade patterns that are subject to significant government interventions. The recent EU-China trade dispute around subsidized solar panel exports and alleged dumping practices bears

[6] For details see www.windpowercluster.com and the case study by Boeckle et al., 2010. The political impetus for building this cluster came from the need to revive a declining industrial region (ship building).

testimony to this feature. Hence, analyzing revealed competitive advantages must be seen with this caveat in mind.

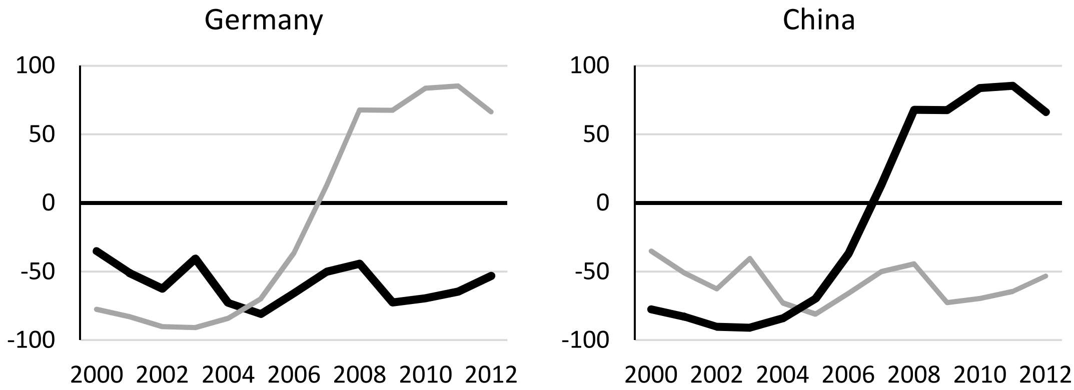
Figures 5 and 6 clearly demonstrate a relatively lower international competitiveness of the German solar PV industry compared to the German wind energy industry. A temporary increase in the world market share up to 2008 (15 per cent) could not be sustained: in 2012, this share fell back to its pre-2005 level of below 10 per cent. Background data show that German exports of solar PV were almost cut in half between 2010 (US$8.1 million) and 2012 (US$4.5 million). Similarly, we can witness a consistent revealed competitive disadvantage over the entire period from 2000 to 2012. In terms of comparator countries, the spectacular rise of China stands out. By 2010, the country was in the leading position in both indicators presented here. Other than the German wind industry, which is under pressure but not endangered by China (Lema et al., 2013), the German solar PV industry has lost its competitive edge.

Figure 5 Solar PV: world market shares (percentage) by country 2000–2012



Source: Authors' calculations based on UNCOMTRADE.
Note: The four diagrams are identical, differing only in the country highlighted.

Figure 6 Solar PV: Revealed Competitive Advantage by country 2000–2012



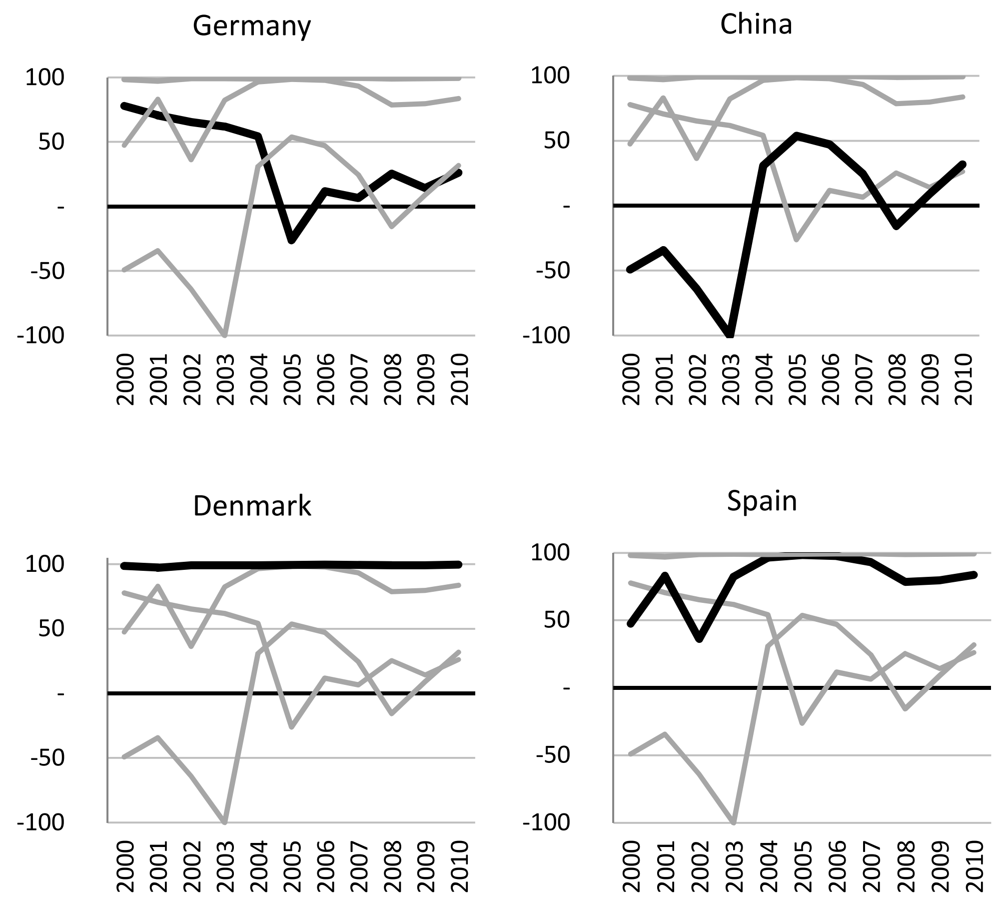
Source: Authors' calculations based on UNCOMTRADE.
Note: The two diagrams are identical, differing only in the country highlighted.

Beyond the aggregate data presented in the charts, the strong competitive position of German PV system component manufacturers and equipment suppliers must be emphasized. Data for 2011 show that the share held by German firms in the global market for specialized PV equipment was as high as 50 per cent, while the market share of PV inverters (converting the direct PV cell current into alternating grid current) stood at 35 per cent (GTAI, 2013, fact sheets).

3.2.2. Technological Innovation

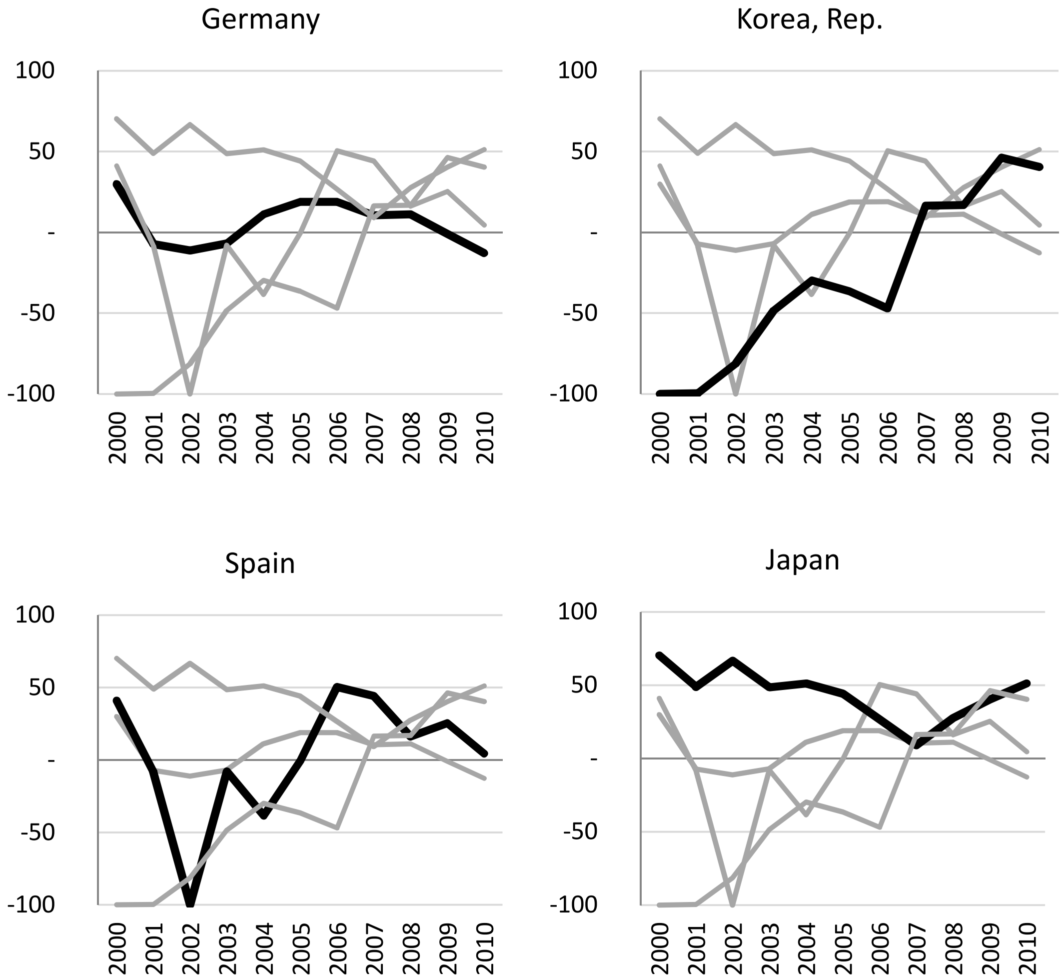
A positive value in Figures 7 and 8 indicates that the technology under consideration has a superior patent (innovation) position compared to the entire technology portfolio of a country.

Figure 7 Wind Energy: Relative Patent Shares by country, 2000–2010



Source: Authors' calculations based on OECD Patent Database.
Note: The four diagrams are identical, differing only in the country highlighted.

Figure 8 Solar PV: Relative Patent Shares by country 2000–2010



Source: Authors' calculations based on OECD Patent Database.
Note: The four diagrams are identical, differing only in the country highlighted.

It emerges that in the case of Germany, wind energy—after a trend reversal in 2005—has consistently achieved a positive RPS (value of +26 in 2010), while the opposite applies for solar PV. From a moderately positive RPS up to 2006, the trend has been downwards resulting in negative RPS as of 2009 (with a value of -13 in 2010). Background data show that between 2005 and 2010, the absolute number of German wind energy patents more than tripled; the number of solar PV patents increased by one quarter.

These results are corroborated by a similar analysis undertaken for 2009 based on European Patent Office (EPO) data (Bointner, 2012) in which the gap between a positive RPS value for wind technology and a negative RPS value for solar PV technology is even more pronounced. They are further substantiated by a recent broader cross-country analysis of green technology patents based on World Intellectual Property Organization's (WIPO) classification (Bierenbaum et al., 2012), which led to the following results (for the 1990–2010 period):

- While trailing behind the U.S. and Japan in terms of the absolute number of "green" patents[7] granted, Germany exhibits the highest per capita green patent intensity of all countries worldwide.
- In wind energy technology, Germany is comparatively stronger as an innovator (measured as share of cumulative global wind patents) than as an adopter (share of installed global wind power capacity) although the difference, with 21 per cent and 14 per cent respectively, is relatively small.
- In solar PV technology, Germany is comparatively stronger as an adopter than as an innovator, with a 44 per cent share of installed global capacity and only 12 per cent share of global cumulative patents.

In general, there seems to be a closer alignment between innovation and deployment trends in the case of wind energy, while for solar PV, innovation and deployment hubs may be decoupled as PV technology is more easily transposable to countries with the most conducive incentives structure for large-scale deployment (Lee et al., 2009). From the same study, it emerges that several German wind energy companies are among the top 20 patent holders (Enercon[8] indeed is number 1, followed by Siemens at number 7) whereas in the case of solar PV patents only Siemens figures at number 20.

3.2.3. Employment Creation

Of the almost 380,000 total jobs created by renewable energies in 2012 (for the first time, down from the previous year), more than half (54 per cent) were accounted for by solar PV (23 per cent) and wind energy (31 per cent) alone (Table 1). Based on the two sources below Table 1, the following structural features stand out:

- While the majority of jobs stem from investments into solar and wind installations, the share of jobs related to maintenance and operation services is growing. This applies in particular to onshore wind, where the share of maintenance and operations jobs is as high as 16 per cent. For solar PV, the same share stands at 10 per cent. Despite the 2012 slump in new solar installations, maintenance and operation jobs kept growing.
- Export markets play an essential role in employment creation. For all renewables, in 2012 the domestic market generated 59 per cent of investment-related jobs, with export markets accounting for 41 per cent. In view of the above-average export ratio of electricity-generating technologies, export-driven employment must be even higher for wind energy and solar PV.
- The regional distribution of employment is more dispersed than often assumed. While there is a basic pattern of more wind installations in the Northern and Eastern coastal regions and a higher solar PV intensity in Southern federal states, component-driven employment is often located in the traditional industrial centres. At the same time, an

[7] According to WIPO's Green Inventory, "green patents" cover alternative energy production patents in 13 sectors: solar, wind, geothermal, biofuel, biomass, fuel cell, hydro, synthetic gas, integrated gasification combined cycle, man-made waste, mechanical power from muscle energy, natural heat and waste heat.

[8] Enercon patents are registered under the name of Aloys Wobben, who founded the company in 1984 and has remained its owner to date.

important inequality-reducing impact is noticeable: In those Eastern federal states suffering from the highest unemployment ratios nationwide (with the exception of city states), the relative importance of solar and wind employment is most pronounced. Specifically, this applies to Mecklenburg-Western Pomerania, Saxony-Anhalt and Brandenburg with unemployment rates (June 2013) of 10.8 per cent, 10.7 per cent and 9.5 per cent, respectively.

- In terms of the skill profile of the labour force (see Table 2), employment in both the solar PV and wind energy industry is very much in line with the comparative advantage of a sophisticated labour market in a high-tech economy like Germany's. While there is a negligible share of unskilled labour, in both the wind and particularly the solar PV industry the share of university-degree staff is around three times as high as the national industry average.

Table 1 Employment created by wind energy and solar PV, 2010–2012

	Investment-related jobs		**Jobs in maintenance and operation**		**Total jobs**	
Year	**2011**	**2012**	**2011**	**2012**	**2011**	**2012**
Wind	82,600	98,600	18,500	19,300	101,100	117,900
- onshore		81,300		18,600		99,900
- offshore		17,300		700		18,000
Solar PV	103,300	78,900	7,600	8,900	110,900	87,800
Total renewable energies	242,000	227,100	75,800	80,700	381,600 [a]	377,800 [a]
Total share of wind (per cent)	34	43	24	24	26	31
Total share of solar PV (per cent)	43	35	10	11	29	23

[a] Includes also jobs created by fuel supply activities (biogas, biomass, biofuel), as well as related jobs in public institutions (R&D, administration).
Sources: Based on data in Federal Ministry for the Environment, 2012; O'Sullivan, Edler, Bickel, Lehr, Peter, & Sakowski, 2013.

Table 2 Skill profile of employment in the wind energy and solar PV sector (survey-based; percentage shares)

	No vocational training	Completed vocational training	University degree
Wind energy	0.9	79.9	27.1
Solar PV	5.8	81.7	34.7
Total industry	15.0	69.5	9.9
Source: Federal Ministry for the Environment (BMU), 2012.			

3.2.4. Environmental Benefits from Avoided Emissions

As emphasized in Section 2, from the outset one of main drivers of renewable energy promotion in Germany has been the political commitment to achieving ambitious goals of reducing greenhouse gas emissions in the fight against climate change, as well as reaching environmental objectives in terms of reducing various pollutants. Hence, the question of exactly what level of avoided emissions can be attributed to the growing deployment of wind energy and solar PV is of particular importance.

In Table 3, we take a look at directly avoided carbon dioxide (CO_2) emissions for which consistent time series data are available. It emerges that between 2005 and 2012 the amount of avoided CO_2 emissions has more than doubled from 23.8 million tonnes to 56.5 million tonnes. The contribution of wind energy and solar PV to reducing Germany's carbon footprint thus is of significance at the broader national level: In 2012, both sectors combined avoided CO_2 emissions amounting to 6.9 per cent of total CO_2 emissions, or 17.8 per cent of CO_2 emissions caused by electricity generation. When considering the entire 2005 to 2012 period, more than one tenth (11.3 per cent) of electricity-related CO_2 emissions could be prevented.

Table 3 Directly avoided CO_2 emissions from wind energy and solar PV, 2005 to 2012 (in 1,000 tonnes)[a]

Year	Wind	Solar PV	Wind plus solar PV	Share of total CO_2 emissions (per cent)	Share of CO_2 emissions from electricity generation (per cent)
2005	23,227	616	23,843	3.3	7.4
2006	24,038	1,341	25,379	2.9	7.7
2007	30,367	1,818	32,185	3.8	9.5
2008	28,989	2,978	31,967	3.8	10.0
2009	28,211	4,435	32,646	4.2	11.2
2010	27,244	7,792	35,036	4.2	11.5
2011	35,239	12,848	48,087	6.0	15.8
2012[b]	35,489	20,998	56,487	6.9	17.8

[a] According to the sources given below, wind avoids 726 gCO_2/kWh and solar PV 613 gCO_2/kWh.
[b] Total CO_2 emissions and CO_2 emissions from electricity generation are estimates.
Sources: Compiled and calculated from AGEE-Stat, 2012; Umweltbundesamt, 2013a; Umweltbundesamt, 2013b.

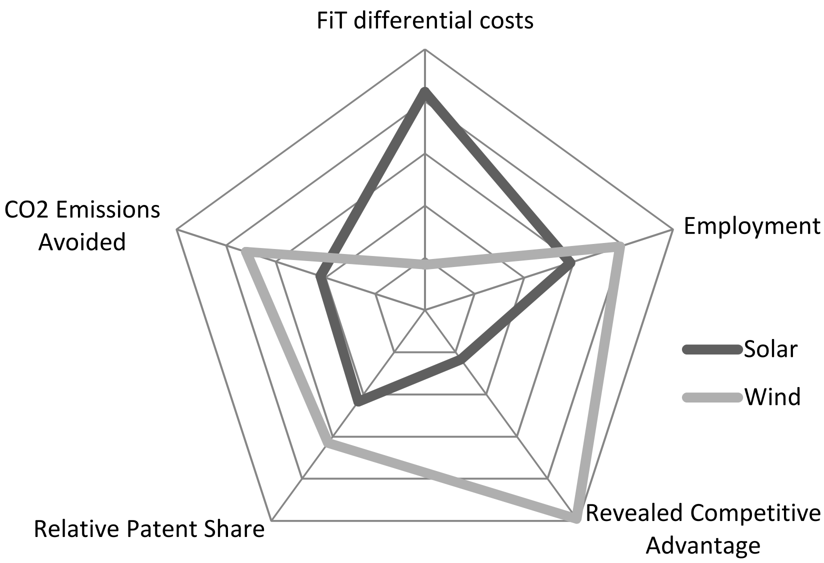
Numerous life cycle assessments of the ecological balance sheet of alternative energy sources have been undertaken in recent years. The overall result of a comparatively much smaller carbon and ecological footprint of wind energy and solar PV than, for example, coal-based electricity, is unequivocal (IPCC, 2011). Relevant data for Germany lead to the conclusion that in terms of CO_2, coal-based electricity generates around 100 times more emissions per unit than wind energy and 10 to 20 times more than solar PV (Krewitt & Schlomann, 2006, p.35).

In assessing the ecological impact of the FiT, it must be noted that greenhouse gas emissions in the European context are traded under the European Emissions Trading Scheme. Any FiT-induced lowering of CO_2 emissions reduces demand for certificates, cuts their price, and thus discourages investments in emission reductions elsewhere (Böhringer & Rosendahl, 2010, 2011). On the other hand, the lower price of certificates opens political space for tighter ETS caps without threatening the competitiveness of companies. Without such tighter caps, however, the parallel operation of FiT and ETS will crowd out the former's emission reduction benefits—at least for those emissions traded under the ETS. Nonetheless, literature finds many arguments for operating both systems in parallel, such as the long term aspect of developing technologies for carbon neutrality (Vogt-Schilb & Hallegatte, 2014), political economy arguments (Jenkins, 2014; Rozenberg et al., 2014), investment certainty for low carbon investments (Lecuyer & Quirion, 2013) and cost reductions through learning and spillover effects (Fischer & Preonas, 2010).

3.3. Contrasting Wind and Solar PV

In Figure 9, a stylized summary of the main quantitative results of Section 3 is presented, complemented by the EEG differential costs as proxy for the additional cost of wind and solar. While not amounting to an objective assessment of each sector, the comparison between wind energy and solar PV would indicate that the wind energy sector is leading in all performance dimensions: employment creation, competitiveness, technological innovation and avoided CO_2 emissions—and does so with lower subsidy levels.

Figure 9 Stylized profile of wind energy and solar PV by performance dimension (latest available years)



Source: Based on Tables 1 and 3, and Figures 2, 4, and 6-8 in this paper.
Note: An appropriate scaling was introduced for each performance dimension. Specifically, the following values were defined as 100 per cent:

- FiT differential costs: 30 €ct/kWh
- Employment: 150,000 jobs
- RCA: 200 (based on -100 to +100 range)
- RPS: 200 (based on -100 to +100 range)
- CO_2 emissions avoided: 50 million tonnes

Also in terms of medium-term projections of the LCoE for wind energy and solar PV in Germany (Fraunhofer ISE, 2012), onshore wind plants are considered to remain the most cost-effective renewable energy technology. Currently at 8 €ct/kWh (at 2000 full-load hours per year), the LCoE for onshore wind energy is forecast to marginally decrease further to 7 €ct/kWh in 2030. While solar PV systems are expected to remain more costly, they are coupled with much faster cost decreases due to a steeper technological learning curve. Overall, this would lead to onshore wind plants becoming cost-competitive with a conventional (fossil plus nuclear) electricity mix by 2017, while the same would apply for ground-mounted solar PV systems by 2022.

The above stylized comparison of solar PV and wind energy has a number of broader industrial policy implications, which will be discussed in Section 4.

4. Conclusions and policy implications

While green industrial policy in Germany targets many sectors (for example resource-efficient environmental technologies, waste management, biofuels production or electro-mobility), the energy transition (*Energiewende)*, with its focus on renewable energy sources is certainly the most prominent national project. It places Germany among the most ambitious countries worldwide in the promotion of a transition to sustainable energy. However, public debate in Germany about the *Energiewende* in general and its different features in particular is highly politicized, and often driven by ideology or vested interests. This paper has sought to provide a balanced assessment drawing on the best available evidence and quantifying explicitly what costs and benefits are excluded or included.

Germany has a variety of policies in place to support the *Energiewende*. Among them are mechanisms targeting all stages of renewable energy technology development from basic research to deployment. The system of feed-in tariffs (FiT) is the core element of Germany's policy package, and as such deserves closer analysis. In the energy policy community, there is widespread agreement that the FiT mechanism in general, and its application in Germany in particular, has proven to be an exceedingly effective policy instrument for pushing renewable energies into the market (Haas et al., 2011; Held et al., 2006; Matschoss 2013). Its efficiency, however, hinges on the appropriate determination of tariff levels. Based on a comparative assessment of renewable energy support policies in its member states, the European Commission concludes that "*well-adapted* feed-in tariff regimes are generally the most efficient and effective support schemes for promoting renewable electricity" (EC, 2008, p.3). Experiences in the emerging countries have shown that competitive bidding may be a suitable approach to identify the actual levels of such well-adapted feed-in tariffs (Becker & Fischer, 2013, Pegels, 2014), and Germany could be well advised to 're-import' some such elements when reforming its own support scheme.[9]

The German FiT scheme is characterized by a long contract period (20 years), guaranteed grid priority, technology-specific tariffs on a degressive scale and recently, provisions for tariff evolution in response to deployment trends (flexible ceiling). These design elements have created a stable investment environment and hence a strong readiness of capital markets to finance renewable energy projects at relatively low interest rates. Furthermore, the technology specificity—with differing FiT subsidy bands for each source of renewable energy—has had the advantage of encouraging the early deployment and upscaling of a wide spectrum of technologies. On the

[9] For a discussion of feed-in tariff reform approaches see Lütkenhorst & Pegels (2014).

downside, it has not allowed for a focus on the most cost-efficient decarbonization technologies. A premium was thus placed deliberately on creating a broad foundation for various renewable energy technologies to develop and become commercially viable. However, this premium seems to have led to a bubble in the German solar PV manufacturing industry. Obviously, the critical challenge is to identify a sufficiently high subsidy level for investments to be triggered without creating excessively high policy rents (Pegels, 2014). This presupposes correct assumptions about future technological learning curves and price trends as a basis for taking well-informed decisions about an optimal tariff degression scale. The assumptions in the case of solar PV did not correspond to the considerable cost reductions of PV installations since 2009.

Figure 9 seemingly presents an unequivocal outcome of the comparison between wind and solar support, showing the superior performance of wind energy for all indicators. However, the policy implications of these empirical findings are less clear-cut than they may appear at first glance. Should all eggs be put into the wind basket? In the direct comparison of wind and solar energy, the answer could be "yes," on grounds of cost-efficiency and broader benefits. Yet just like in the case of financial investments, there are advantages to be had from diversification. Hence, Figure 9 needs to be interpreted dynamically and from a systemic perspective. While wind energy currently performs better, the data presented is only a snapshot. It may be wise to also support solar PV and, for that matter, a variety of other sources of renewable energy. The technology learning curve of solar PV may still promise strong cost reductions, while wind energy is already mature (Diekmann et al., 2012b). The solar resource and thus deployment potential in other world regions may further support these reductions. Once a particular energy source achieves grid parity, deployment may increase steeply and give other performance indicators a boost as well. Technologies in their earlier stages may also hold a higher potential for innovation than their mature counterparts. This includes solar PV, but also such other early stage renewables as offshore wind or tidal and wave energy. Innovation as an aim of green industrial policy could thus benefit from the diversified support of renewable energy technologies.

However, diversification as such does not guarantee success in fostering innovation and competitiveness. Has the German policy-induced creation of a lead market led to a first-mover advantage or disadvantage?[10] Is it more a question of the early bird catching the worm or the second mouse getting the cheese? On the one hand, Germany has succeeded in building up world-class renewable energy technologies and has captured large segments of the world market. If well exploited, this lead position can secure competitiveness, employment and positive innovation dynamics for years to come. On the other hand, there are strong elements at play here of other countries appropriating part of the benefits of Germany's lead market role. This may be seen as a "successful internationalization of the photovoltaic strategy (and) . . . a tribute to Germany's contribution to meeting global energy and climate challenges" (Diekmann et al., 2012a, p. 3). Alternatively and in a more pointed manner, the verdict may be that "German households have, through the renewable subsidies they pay, made the world a gift of solar technology which China has now been happy to exploit" (Buchan, 2012, p.4).

[10] For a more thorough discussion of lead market strategies see the results of the *Lead Markets* project of the Centre for European Economic Research (ZEW) at http://kooperationen.zew.de/en/lead-markets/project-description.html.

It is hard to escape the conclusion that the deployment of solar PV in particular has in recent years been out of line both with its long-term expansion potential and its reasonable relative weight within the renewable energy mix—in a country with less-than-ideal climatic conditions for heavy reliance on solar energy. Also, in the harsh judgment of Eicke Weber, Director of Fraunhofer ISE, "Germany's energy policy has created a market for photovoltaics—not an industry" (Paris Tech Review, 2012, p.5). This indicates that deployment under the soft conditions of heavy subsidies was given priority, without sufficient attention to forming an innovative industry pushing the technological frontier. In a nutshell: expansion was put above upgrading.

However, at the broader level of the energy system and within a supply scenario increasingly based on renewable energy, a variety of different intermittent sources in the electricity grid are required to support overall grid stability—the sun may shine when the wind does not blow. This contributes to security of supply, in particular if investments in transmission lines keep pace and connect geographically dispersed locations of renewable electricity generation. Unfortunately, German investments in grid expansion and solutions for electricity storage lag behind requirements.

The systemic perspective cannot, however, be restricted to renewables: the energy sector must be seen in its entirety. The pace of German renewable energy deployment has taken many actors by surprise. This has led to unintended effects on energy planning, which in turn affect the overall aims of green industrial policy, in particular its environmental dimension. To safeguard energy security, Germany currently operates two energy systems in parallel: a base-load focused, centralized and fossil fuel-based system; and an intermittent, decentralized and renewable system. These systems increasingly interact. To compensate for the phasing out of nuclear power, the German government has decided to support highly efficient new coal and gas fired power stations, financing this support out of the Energy and Climate Fund (Deutsche Bundesregierung, 2012). Together with the unexpectedly high generation from renewable sources, Germany currently produces much more electricity than it consumes. In 2012, electricity exports exceeded imports by a record level of 22.8 terawatt hours (TWh), up from 6 TWh in 2011 and 17.6 TWh in 2010 (Statistisches Bundesamt, 2013). This oversupply, combined with low input prices and the low price of carbon emission certificates traded under the European Emissions Trading Scheme, reduces electricity prices to the extent where at times only the cheapest sources are still competitive, that is, hard coal and, in particular, lignite in the case of Germany. Lignite, however, is exceedingly damaging to the environment and human health. As a result, total German carbon dioxide emissions have been stagnating in the past four years, and even rising in 2012 (Umweltbundesamt, 2013b). Paradoxically, the rapid deployment of renewables thus does not currently lead to decreasing total greenhouse gas emissions.

At the same time, the low electricity prices at the electricity stock exchange do not improve the competitive position of small and medium enterprises. Including 99 per cent of German enterprises and providing more than 60 per cent of jobs (May-Strobl & Haunschild, 2013; BMWi, 2012), the *Mittelstand* is widely considered as the backbone of Germany's economy. However, their electricity prices are among the highest in Europe—at least partly due to the added cost of renewables (DIHK, 2012). The blow to the competitiveness of the largest electricity consuming companies is softened by exemptions from the electricity surcharge. These, however, call the equity of the current support system into question, since they raise the burden on households and small and medium enterprises.

To reach the broader aims of green industrial policy and manage the energy transition effectively, Germany will need to address the systemic challenges outlined above. Special emphasis is to be put on three broader dimensions: institutional fragmentation, interacting policy schemes and transformational alliances.

Institutional Fragmentation

As discussed by Zelli (2001) and Zelli and van Asselt (2013) in the context of climate governance, institutional fragmentation may have negative implications for effectiveness, legitimacy and fairness of policies. Since the promotion of wind energy and solar PV in Germany is part of a much more fundamental agenda of transitioning to a decarbonized development trajectory, issues of institutional fragmentation and distributed responsibilities are particularly relevant. The contribution of renewables to electricity generation has reached proportions that call for simultaneous policy attention to capacity expansion, competitiveness, technological innovation, grid management and storage capacities, i.e., a systemic perspective. However—and this may be surprising for a country often portrayed as a poster child of institutional effectiveness—the current institutional setup leaves a lot to be desired. Several federal ministries have important roles to play, and specialized subsidiary agencies are proliferating. There is thus a strong case for pooling the political responsibilities. This could be all the more important given that in the typical German scenario of a coalition government, there is a high likelihood of interlinked functions being spread across political party lines.

Interacting Policy Schemes

The FiT policy tool as the cornerstone of Germany's energy policy is not operating in complete isolation. In fact, it runs parallel to the European Emissions Trading System (ETS). The interactions between both policy spaces thus need to be analyzed. On the one hand, it can be argued that any FiT-induced lowering of CO_2 emissions would lead to the availability of additional certificates, which, once sold, would generate corresponding emissions elsewhere. On the other hand, the political decision of where exactly to fix a cap for emissions may itself be partly influenced by anticipating trends of future renewables capacity (Lechtenböhmer & Samadi, 2011, p. 10). In essence, the parallel operation of FiT and ETS will crowd out most of the former's emission reduction benefits—not, however, the other benefits it creates.

A second dimension of policy interaction is related to transcending national boundaries. Quite obviously, the multiplicity of national FiT schemes, for example in the European Union, is an ineffective response to the potential of a unified European energy policy. A unified European, or even trans-Mediterranean, grid could largely balance out inherent grid instability caused by intermittent renewable energy sources. At the same time, there is a danger of a conceivable common approach being designed as the lowest common denominator of conflicting country interests. As a result, the more ambitious energy policy of Germany as a lead market for renewables may be severely compromised.

Transformative Alliances

Rightly or wrongly, green industrial policies in Germany are almost equated today with the energy transition. We are dealing with a national project of the first order. There are winners and losers, proponents and adversaries. In this economically and politically highly charged setting, the formation of transformative alliances and the definition of a compelling narrative are key (Schmitz et al., 2013). Such alliances may see unlikely bedfellows. Just as parts of the business establishment are embracing the transition and investing into the energy technologies of the future, heavy resistance is coming from parts of the traditional green movement. Alliances will thus have to go beyond conventional boundaries.

Having created the largest lead market for upscaling deployment and having brought down prices of renewables is not going to be a winning argument in the public discourse. The German FiT-driven renewables revolution may have been “arguably the most successful development cooperation programme ever in this field” (Hombach, 2013), making off-grid renewable electricity affordable in remote areas of developing countries. However, this is not the yardstick used by the German public at large when assessing costs and benefits. In Germany, any transformative alliance can only succeed if it builds on a platform of employment, competitiveness and innovation – a platform that is currently endangered both by the emotionally charged debate around imports of solar PV panels from China (Schmitz, 2013, p. 9) and the debate around electricity price hikes. Furthermore, the creation of decentralized energy systems and hence strengthened regional and local economic structures (above all in economically weak regions) should be highlighted more than hitherto.

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