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The stuttering energy transition in Germany:

Wind energy policy and feed-in tariff lock-in

Johan Nordensvard and Frauke Urban

Abstract: This article aims to examine whether the formulation of specific low carbon policy such as the feed-in tariff for wind energy in Germany can partly be a barrier to a comprehensive energy transition (Energiewende). Despite their short and medium-term success, these policies could create a long-term lock-in if they are formulated in a way that leads to a stagnation of systems innovation. The research finds that while the share of wind energy has increased rapidly over time, the feed-in-tariff and other low carbon policies and incentives have not been sufficient to achieve a socio-technical regime transition in Germany yet. We suggest that the German feed-in-tariff has incorporated wind energy (a niche-innovation) and wind energy actors (pathway newcomers) into a slightly modified socio-technical regime that is rather similar to the earlier 'fossil fuel dominant' socio-technical regime.

Keywords: Wind energy, Germany, Energy Policy, National Innovation Systems

1 Introduction:

This article aims to examine whether the formulation of specific low carbon policy such as the feed-in tariff for wind energy in Germany can partly be a barrier to a comprehensive energy transition (Energiewende).Despite their short and medium-term success, these policies could create a long-term lock-in if they are formulated in a way that leads to a stagnation of systems innovation. Lock-ins and path dependencies have often been used to describe barriers for transitions to sustainable and low carbon energy technologies.

Wind energy is considered an important technology in Germany to spearhead the Energiewende to sustainable and low carbon energy resources. However in Germany the policies and financial incentives that aim to support the development, production and use of wind energy are widely debated.

Germany is a global forerunner in innovation in renewable energy, particularly in wind energy. Germany is currently Europe's largest wind energy market and the world's third largest wind energy market, after China and the United States (US) (GWEC, 2014). Germany had an installed capacity of more than 34 GW by the end of 2013. This accounted for about 30% of the European installed wind capacity in 2013 (GWEC, 2014; IEA, 2014). Germany's installed capacity and market has been growing continuously since the mid-

1990s (BWE, 2012; IEA, 2014). Germany has both considerable onshore wind capacity and a rapidly growing offshore capacity. The German government has targets in place for a share of 35% renewable energy among the final electricity consumption by 2020, 50% by 2030 and 80% by 2050, of which wind plays an important role (BMU, 2012; BMU, 2011). The market shares of wind firms in Germany are as follows: about 60% Enercon, 20% Vestas, 10% REpower, 4% Nordex, 2% Bard, remaining 4%: others, including e.n.o., Vensys, Siemens GE Electric and AREVA (Lema et al, 2014).

Despite its leading role in global wind energy, Germany's wind energy industry remains understudied from an academic perspective. Earlier studies cover important ground, however they are mostly limited in terms of their geographic scope (e.g. focusing on one specific region in Germany) or they adopt a narrow perspective (e.g. public perception of wind energy or costing of wind energy). For example, Jobert et al (2007) and Musall and Kuik (2011) discuss the local acceptance of wind energy in Germany. Portman et al (2009) examine offshore wind energy by comparing Germany with the US. Drechsler et al (2012) focus on the feed-in tariffs in Lower Saxony in Northern Germany, while McKenna (2013) discusses the determination of cost–potential-curves for wind energy in the federal state of Baden-Wurttemberg. Nicolosi (2010) discusses the wind power integration and power system flexibility in extreme weather events in Germany.

This paper is based on empirical research for the research project 'Technological Trajectories for Climate Change Mitigation in Europe, China and India'. This study builds on fieldwork entailing in-depth qualitative interviews with 18 key actors from (wind) energy firms, business associations, research organisations and government authorities. The interviews were conducted by the authors in 2012 and 2013 at various sites in Germany. Taking wind energy as an example, this article aims to elaborate the potential path dependency and lock-in that could hinder the Energiewende. The paper examines the role German wind energy policy has played in creating a long-term transition to a new socio-technical system of renewable energy. The unique aspect of the paper is to look closer at the German wind energy sector using the framework of socio-technical systems and to elaborate whether a lock-in has occurred caused by the way wind energy policies are designed.

The argument of the paper is as follows: Existing wind energy policies have led to an upscaling of wind energy capacities and a recent emphasis on expensive and risky off-shore projects. Current German wind energy policy has creates two financial dilemmas: First, it has pushed up energy costs for consumers through the feed-in-tariff which is funded by increases in consumer electricity prices, second it has lowered energy costs for energy-intensive industries through feed-in-tariff exemptions. This has created an unequal burden for consumers. Moreover, we find there has been a lack of policy interest to remove existing barriers for wind energy such as an outdated and under-funded grid system, the overall limited policy framework for electricity distribution from North to South and a lack of regulation to create a fairer division of costs between the state, industry and the consumers. We suggest that the German feed-in-tariff has incorporated wind energy (a niche-innovation) and wind energy actors (pathway newcomers) into a slightly modified socio-technical regime that is rather similar to the earlier 'fossil fuel dominant' socio-technical regime.

We conclude further that there is a feed-in-tariff lock-in that has created an overt focus on increasing wind energy capacity (increasing output) rather than promoting innovation in renewing the grid systems and increasing the balance of wind energy supply and demand between the North and the South or creating a balanced funding system that also includes contributions from the industry and the state. The funding has been withheld from priority areas, such as grid systems that are now the financial, political and technical barrier to a large-scale successful energy transition.

Section 2 elaborates the conceptual framework and the methodology. Section 3 presents a literature review of the German wind energy case, section 4 discusses the results from our empirical research and concludes the paper.

2 Methods

2.1 Introduction to key concepts

Innovation can be broadly defined as creating something new, developing a new product, service or idea. We here refer to innovation more narrowly as new products, services and ideas that have successfully reached the market (Rogers, 2003). *Wind energy innovation systems* relate to wind power generation (e.g. core technology and components for wind turbines), transmission and distribution (e.g. grid systems), as well as systems that relate to the deployment of wind energy (e.g. offshore/onshore). Innovation systems also include broader issues beyond the hardware, such as skills, expertise and knowledge (Urban et al, 2012).

Energy transitions are shifts from a country's economic activities based on one energy source to an economy based (partially) on another energy source. Several energy transitions have occurred in history, mainly in developed countries: The energy transition from manpower and animal power to traditional biomass (such as fuel wood, crop residues, dung), from traditional biomass to coal (ca. 1860), from coal to oil (ca. 1880), from oil to natural gas (ca. 1900), from natural gas to electricity and heat (ca. 1900-1910), the large-scale commercial introduction of nuclear (ca. 1965), the large-scale commercial introduction of renewable energy and large hydro power (ca.1995) (Bashmakov, 2007). Energy transitions are characterised by changing patterns of energy use (e.g. from solid to liquid to electricity), changing energy quantities (from scarcity to abundance or the other way around) and changing energy qualities (e.g. from fuel wood to electricity) (Bashmakov, 2007).

Energiewende refers to the German government-led energy transition that aims to reduce dependency on fossil fuels, particularly coal, and at the same time phase out nuclear power by 2021. It is heavily based on renewable energy, most importantly wind energy. A successful energy transition in Germany involves the following government targets: a share of 35% renewable energy among the final electricity consumption by 2020, 50% by 2030 and 80% by 2050 (BMU, 2012; BMU, 2011). An incomplete, partial energy transition would not achieve these goals, but would still have a share of renewable energy among the final electricity consumption.

The *feed-in-tariff* is a financial instrument to increase the share of renewable energy among the total energy mix. For onshore wind energy the tariff is currently 8.93 EUR ct/kWh for the first 5 years + 0.48 EUR ct/kWh bonus = 9.41 EUR ct/kWh for first 5 years, then 4.87

ct/kWh. For offshore wind energy the tariff is 15 ct/kWh for the first 12 years, then 3.5 ct/kWh or alternatively 19 ct/kWh for the first 8 years (in late 2014) (Lema et al, 2014).

2.2 Socio-technical regimes and lock-in

Berkhout et al (2010) present the concept of *socio-technical regimes* which describe "stable and ordered configurations of technologies, actors and rules that represent the basis for social and economic practices" and includes "a complex web of technologies, producer companies, consumers and markets, regulations, infrastructures and cultural values" (Berkhout et al, 2010:263). This is very much linked to the different development pathways that countries can take and that are constituted by a set of interlocking and interacting socio-technical regimes (Berkhout et al., 2010). From this perspective, energy systems could be described as "socio-technical configurations where technologies, institutional arrangements (for example, regulation, norms), social practices and actor constellations (such as user–producer relations and interactions, intermediary organisations, public authorities, etc.) mutually depend on and co-evolve with each other" (Rohracher and Späth, 2014:1417)

Geels finds that socio-technical regimes consist of three different but interlinked dimensions that include a) network of actors and social groups, b) regulative, normative and cognitive rules and c) material and technical elements (Geels, 2002). Innovation should therefore not be seen as just a narrow policy or economic matter but it could here be understood as interwoven with complex social, political and economic arrangements. Nation states are often not able to freely choose any possible pathway but Unruh argues that socio-technical regimes often mean path dependence and lock-in (Unruh, 2000).

Lock-in is here defined as a form of inertia created by a specific system. One differentiates between technological lock-in and carbon lock-in, although both are closely intertwined. Inertia within a specific innovation path over time can lead to the development of a technological paradigm that may be locked-in (Dolfsma and Leydesdorff, 2009). Foxon suggests "technological lock-in is the idea that, as economic and cultural advantages accrue to existing incumbent technologies, barriers are created to the adoption of potentially superior or at least as valuable alternatives." (Foxon, 2014:123). This makes switching to alternative technological systems very difficult (Altenburg and Pegels, 2012).

Unruh suggests lock-in is driven by the process of „technological and institutional co-evolution driven by path-dependent" economies of scale (Unruh, 2000: 817). Lock-in happen due to the complex interactions of governing bodies and innovation and technological systems. Lock-in creates "persistent market and policy failures that can inhibit the diffusion of carbon-saving technologies despite their apparent environmental and economic advantages" (Unruh, 2000: 817). With regards to high carbon development, carbon lock-ins are created by the fossil fuel-dominated energy system and the fossil fuel-dominated societal and economic model that results in investments, infrastructure and emission trajectories being locked into high carbon pathways for decades and thereby preventing low carbon transitions (Unruh, 2000). Carbon lock-in plays a role as the investments and the infrastructure for energy may be tied to high carbon pathways for decades due to the long construction times and life times of fossil fuel power plants, as well as the associated high investments and running costs. While carbon lock-in was mainly a phenomenon experienced by industrialised countries in the past (Unruh, 2000; Unruh, 2002); the rise of emerging economies and emerging emitters such as China and India has led to a 'globalisation' of lock-in (Unruh and Hermosilla, 2006:1185). Unruh argues that an escape from carbon lock-in is needed, however this requires exogenous forces and is likely to be incremental, rather than a linear process (Unruh, 2002). Some leading scholars therefore speak of large-scale green transformations that need to happen to overcome this lock-in (Scoones et al, 2014).

Path dependency is here defined as a specific form of lock-in that depends on historic technological, institutional, political, social and economic trajectories that will continue to be pursued in the future. Path dependency is linked to technological inter-relatedness (e.g. developing state-of-the-art fossil fuel technology rather than renewable energy technology or developing state-of-the-art combustion cars rather than electric vehicles), economies of scale (e.g. large-scale energy generation, motorways and urban road infrastructure) and quasi-irreversibility (e.g. dependency on energy generation and cars) (Berkhout, 2002). As most of the world's modern energy systems are based on fossil fuels, there is a high likelihood that this dependency on fossil fuels will continue into the future, if we do not intervene actively and transition towards low carbon technologies. Most of the world's systems are built to sustain a path dependency based on fossil fuels. Changing fossil fuel path dependency would require a major shake-up of the system, mainly from a political and social perspective as many of low carbon energy technologies, such as wind energy, are technically mature and increasingly cost-effective. Most importantly, governments and firms need to be fully committed to new socio-technical regimes (Berkhout, 2002).

Some suggest that lock-in and path dependency is "characterised by a resistance to change (which, for example, may cause promising new technologies to fail)" (Späth and Rohracher, 2012:465). There is an on-going discussion whether niche-innovations within specific socio-technical regimes could appear within specific 'windows of opportunity'. Niche-innovations could both demonstrate and offer alternatives if they are stabilised and have gathered momentum (Berkhout et al, 2010). It is implied in the discussion that the growth and momentum of a 'niche-accumulation' could in the end lead to undermining the existing socio-technical regime (Berkhout et al, 2010:266). When a socio-technical regime is changing this is often proceeded by a period of uncertainty. Berkhout et al argue that this period is characterized "by the co-existence of multiple niche-innovations, hybridisation and widespread experimentation" and "novel socio-technical configurations emerge as dominant alternatives, leading to a major restructuring of the system (new actors, guiding principles, beliefs and practices)" (Berkhout et al, 2010:266).

We suggest that resistance to change might not lead to a failure of a technology such as wind energy in all cases, but rather to partial failure to achieve an energy transition.

2.3 Methods

The research question for this paper is: What role has the formulation of German low carbon policy, particularly the feed-in-tariff for wind energy, played in creating a possible path dependency and lock-in that can be a barrier to a long-term transition to a new socio-technical system of the Energiewende? The conceptual framework is embedded in the theories of innovation systems, socio-technical regimes and energy transitions. The methods applied were key informant interviews, policy analysis, data analysis and literature review. The policy information was derived from a literature review to analyse the German energy policies and industrial policies relevant for the wind energy industry. This involved a review of existing literature and data. In addition, the authors conducted key informant interviews in Germany in 2012 and 2013 to gain a politically informed understanding of the wind energy industry in Germany. Key informants were experts who are well aware of key trends, technological developments, actors and policies in the wind. The three key stakeholder groups for this research were 1 government, 2 businesses and 3 civil society. For this research, civil society organisations were limited to research institutions and non-governmental organisations (NGOs) that are relevant for wind energy policy-making. Business associations such as wind energy associations were categorised as part of the business stakeholder group.

This fieldwork involved in-depth qualitative interviews with 18 experts from (wind) energy firms, business associations, research organisations and government. The interviewees were selected based on their leading positions in their organisations and their expertise in relation to the Germany wind energy industry. Representatives from the following organisations were interviewed: AREVA (wind energy firm), BMU (German Federal Ministry for the Environment, Nature Conversation, Building and Nuclear Safety), BMWi (German Federal Ministry for Economic Affairs and Energy) Bosch Rexroth (component supplier firm), CEwind (research organisation), Enercon (wind energy firm), EWE (energy firm), ForWind (research organisation), Greenpeace (NGO), IOEW (research organisation), REpower (wind energy firm), Vattenfall (energy firm), VDMA Power Systems (business association), Vensys (wind energy firm), Vestas (wind energy firm). Several interviewees came from the same organisation.

The interview questions were semi-structured, qualitative questions. The interviews in Germany were conducted in German and then translated into English. Information which is not referenced in this paper is derived from the interviews. Additional data on the German wind energy industry comes from organisations such as the German Wind Energy Association BWE, the European Wind Energy Association EWEA, the Global Wind Energy Council GWEC and the International Energy Agency IEA.

3 Results

Table 1 indicates the characteristics of the German wind energy systems. This is being elaborated below with regards to the Renewable Energy Law and the feed-in-tariff, North South wind supply and demand distributionand onshore/offshore wind.

Characteristics of the German wind energy system	**Challenges**	**Opportunities**

Large onshore wind capacity	Lack of land, up-scaling of turbine sizes and capacities, pressure to go offshore	Growing of off-shore wind sector, development of large turbines
High quality turbines	High costs	High quality innovation
Business models selling the 'availability of wind' rather than only hardware	Feed-in-tariff pays per kWh, need to increase electric output	Innovation in business and deployment models
Up-scaling of turbine sizes, capacities, wind farms	Feed-in-tariff pays per kWh, need to increase electric output	Innovation and investments in large turbines and offshore projects at the expense of investments in grids and other technologies such as low wind speed turbines
Rapid growth of offshore sector	Financial and operational risk, little experience	Higher financial incentives through feed-in-tariff, innovation in offshore projects
Offshore sector depended on large (multi-national) utilities	Traditional wind firms being pushed out of / not entering offshore market	Large investments available
Aging, under-performing grid	Cutting edge wind energy innovation cannot maximise full potential with under-performing grid	Creating a modern, high quality grid system
Unequal distribution of wind resources between North and South	Lacking grid expansion for onshore and offshore, lacking grid integration for offshore	Creating a modern, high quality grid system
Unequal demand for electricity between North and South	Lacking grid expansion and integration, long-distance transport of electricity with outdated grids	New market for low wind speed turbines in Southern Germany

Table 1: Characteristics of the German wind energy systems, its challenges and opportunities.

What role has German wind energy policy played in creating a path dependency and lock-in that hinders a long-term transition to a new socio-technical regime of renewable energy?

3.1 The Renewable Energy Law and the feed-in-tariff

The boom in wind energy in Germany is partly driven by national political decisions. This is based on the political aim to phase out nuclear energy by 2021 (BMU, 2011) and to replace both nuclear energy and fossil fuels by renewable energy for the government-led Energiewende. The Energiewende is driven by the Renewable Energy Law (Erneuerbare-Energien-Gesetz EEG) and the legislation for feed-in-tariffs of 1991, 2000, 2004, 2009, 2010, 2012, 2014. The EEG is seen as the cornerstone and key instrument for driving forward national innovation in wind energy in Germany, as all interviewees suggest. Table 2 shows details about the feed-in-tariff and key current policies

Germany	• Renewable Energy Law EEG • Renewable energy to make up 35% of final electricity consumption by 2020, mainly from wind and solar (in 2011 almost 20% had already been achieved). • German feed-in tariff: o Onshore wind energy: 8.93 EUR ct/kWh for the first 5 years + 0.48 EUR ct/kWh bonus = 9.41 EUR ct/kWh for first 5 years, then 4.87 ct/kWh. o Offshore wind energy: o Model 1: 15 ct/kWh for the first 12 years, then 3.5 ct/kWh o Model 2: or alternatively 19 ct/kWh for the first 8 years.

Table 2: National wind policies and the feed-in-tariff in Germany. Source: DEA 2014; BMU 2012; Lema et al, 2014.

Another policy support is the modification of the Federal Building Code since 1997, which made a rapid and uncomplicated development of wind energy possible. Since the building law was changed in 1997 wind turbines were given a privileged status (Jobert et al, 2007). Local authorities can “be forced to accept wind turbines on their territory” but they also have the power to assign “zones for wind energy farms, concentrating them on one appropriate site” (Jobert et al, 2007:2753)

Policies and financial incentives play an important role in shaping the German wind energy innovation path. The German Renewable Energy Law EEG and the feed-in-tariff created a stimulating enabling environment for the wind energy industry, which grew rapidly after the introduction of these frameworks. All interviewees, across businesses, government and academia, strongly affirm that without the EEG and the feed-in-tariff the German wind energy industry would not have grown as substantially as it did and Germany would not have become Europe’s largest wind energy market. Even though the Energiewende and promoting wind energy is high on the agenda of the German government, there is concern that the current feed-in-tariff incentives are too generous and that electricity prices have recently become too expensive (Lütkenhorst and Pegels, 2014).

The interviewees highlighted some disagreement on how the EEG feed-in-tariff favours offshore investment since the feed-in-tariff is awarded per kWh. One energy firm interviewee highlighted that the feed-in-tariff for offshore is higher in the first years and lower in the later years than for onshore, albeit the long-term financial incentives would be similar to onshore. However when calculating the differences based on the feed-in-tariff (see table 2) it is clear that the financing model 1 for offshore wind energy can in fact yield double the financial incentives over a 15 or 20 year period with turbines of the same size and the same kW/h output than onshore, while for financing model 2 the difference is about 50% compared to onshore (DEA 2014; BMU 2012). The investment costs for offshore however are currently twice as expensive as for onshore, which again offsets some of the additional gains from the higher feed-in-tariff incentives.

Most of the interviewees argue that long-term stability for wind energy firms and energy providers is dependent on the EEG and there is concern about the EEG's reform in the coming years. The 2014 reform of the EEG reduced the financial incentives slightly, but there is concern among experts that the tariff might be withdrawn completely. Most of the interviewees, particularly those from wind energy firms, hope for a status quo: they suggest that the policy and financial frameworks for wind energy in Germany are sufficient and should not be amended. There is therefore an undercurrent of insecurity among the experts since many of them expect that the feed-in-tariff policy and the tariffs paid will change or might even be abolished in the near future.

The German feed-in-tariff has become the lifeline for an ever expansive production of new wind energy capacity, a sector thriving due to national subsidies while there is a shrinking political will to upkeep the costly feed-in-tariff system in its current form. A recent appraisal by the expert committee *Research und Innovation* (EFI) concluded that the EEG and the feed-in-tariff policy has led to a high increase of renewable energy: from 7% of the electricity supply in 2000 to 23% in 2012 – see figure 1, and an estimates 30% in 2014 (EFI, 2014).

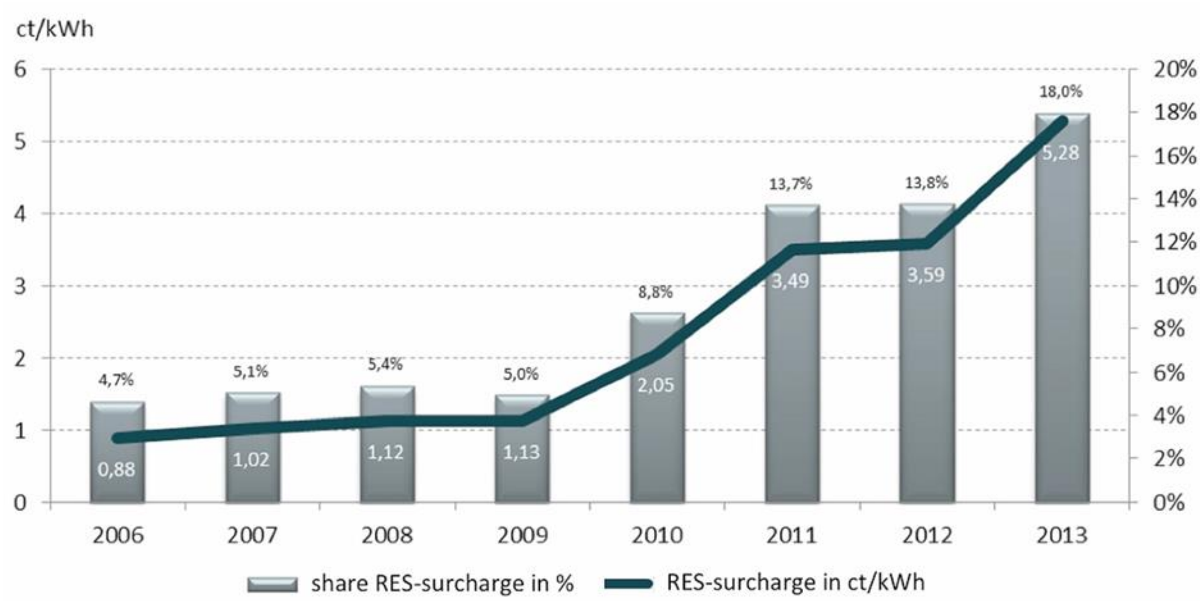

Figure 1: Increase in renewable energy surcharge in Euro ct/kWh based on feed-in-tariff and increasing percentage of share of renewabel energy among the electricity mix in Germany. Source: EFI, 2014

The feed-in-tariff for renewable energy (EEG-Umlage) receives no funding from the state and is not subsidised through public funding or tax funding. It is funded through consumer prices. Similar to minimum wages the government sets the absolute minimum price for electricity from renewable energy. Operators of renewable energy sites such as wind energy farms receive a specific sum of possible reimbursement for the feed-in electricity. The wind energy electricity is then sold on the stock market to generate profits. The feed-in tariffs is supposed to cover the difference between revenues and costs (IWR, 2014). The major challenge is that even if the feed-in tariff for renewable energy had been stopped this would not mean that electricity prices would be sinking. The prices are actually rising. This can be explained by the fact that the government is giving exemptions from the feed-in-tariff to energy-intensive industries, such as the car industry and other large manufacturing industries, which has meant a rise of costs from 1 billion to 5 billion Euros by 2014. Industries that use large electricity quantities are only paying 0.05 ct/kWh for the feed-in-tariff (virtually an exemption) compared to the 6.17 ct/kWh for private households (IWR, 2014). The quota for industries to receive this reduction in electricity prices has sunk from an electricity consumption of 10 GWh to 1 GWh which means that the overall national industry payment into the EEG account will decrease and the costs of the Energiewende will have to be shouldered by the individual consumers (IWR, 2014). Ironically, the way the EEG and the feed-in-tariff were reformed in 2010 has led to the consumer being the economic looser while large firms, utilities and large energy providers are the economic winners of the energy /transition towards renewable energy in Germany. An increased share of wind energy and other renewables has indeed lowered energy prices, albeit only for large corporate customers and energy providers, not for the individual consumer (IWR, 2014).

The rise of renewable energy on the stock exchange has led to lower wholesale prices for renewable energies. Before 2010, suppliers had to supply the municipal utilities directly with renewable energy. This changed in 2010 when renewable energy had to be sold on the stock market. Municipal utilities are now being supplied with conventional electricity and since more renewable energy is sold on the stock market this also means a lowering of prices (IWR, 2014). The lowering of the wholesale energy prices due to the increasing share of renewable energy has led to energy-intensive industries profiting. The lower costs of electrcity from renewables are however not passed onto the consumers as most electricity providers do not buy electricity on the stock market but most of them secure full-supply contracts according to fixed prices. The changes to the EEG are then added to the top of the consumer price (IWR, 2014). The total subsidy is currently about €20bn/year, which amounts to €218/year per household on top of the normal electricity bill (Brunekreeft, 2014). At the same time the costs paid by taxpayers and the government to the operators/energy providers has increased from 1.6 billion Euros in 2001 to 22.9 billion Euros in 2013. See Figure 1. The EFI reports that by 2014, one fifth of Germany's average energy costs are due to the feed-in-tariffs. This has led to a critical public discussion about the legitimation of the EEG and the feed-in-tariff (EFI, 2014:2).

While the feed-in-tariff has substantially increased the output of wind-based electricity in Germany, it has diverted funding and attention away from other priority areas, such as grid systems. This has two implications:

First, beyond the feed-in-tariff, relatively little funding exists for other wind-related innovation, such as grid systems or low-wind speed area turbines. Making the output-based feed-in-tariff the main financial instrument to support wind energy and indirectly promote up-scaling of turbines and projects has meant that few other financial incentives are available for wind energy innovation. This means that the government, wind energy firms, utilities, universities and research centres have spent less on R&D in other areas.

Second, the overt attention of the feed-in-tariff and increasing wind energy output has neglected the fact that the German grid system is ageing, under-performing, under-financed and in urgent need of an overhaul. While government, wind energy firms, utilities, universities and research centres focussed on innovation and funding for large-scale wind turbines and projects little attention was paid to the fact that the increasing wind energy capacity can only be efficiently distributed and transmitted with an adequate grid system. As the German wind energy capacity has rapidly risen in recent years it is now occurring to wind energy experts, firms and even the government that the grid is the major problem. This is particularly the case as the North is experiencing an over-capacity of electricity generated from wind while the South is experiencing in under-capacity but an electricity shortage. Hence long-distance transmission is needed; however the grid has been neglected for decades.

The next sections will discuss onshore wind energy, offshore wind energy and grid issues.

3.2 Onshore

The German onshore wind market is made up of German market leader Enercon, Danish Vestas, Indian-owned REpower, German Nordex, German-owned but Danish-based Siemens and other firms with lower market shares such as German e.n.o., American GE Electric and Chinese-owned Vensys (70% owned by Goldwind) (Lema et al, 2014). While the German wind energy industry dates back to the early 1980s, it has thrived since the introduction of the EEG and the feed-in-tariff in the 1990s. As a comparison, in 1990 Germany had an installed wind energy capacity of only 55 MW, while it had an installed wind energy capacity of more than 34,600 MW in 2013 (IEA, 2014). Figure 2 shows the steep increase in wind energy capacity in Germany from 1990-2013. About 98.5% of this generating capacity comes from onshore wind energy, while only about 1.5% of Germany's wind capacity currently comes from offshore wind (IEA, 2014). The data in figure 2 shows that the EEG and the feed-in-tariff have been instrumental in promoting the German wind energy sector. Lack of land means turbine sizes and capacities have to be up-scaled and offshore developments are being favoured in recent years.

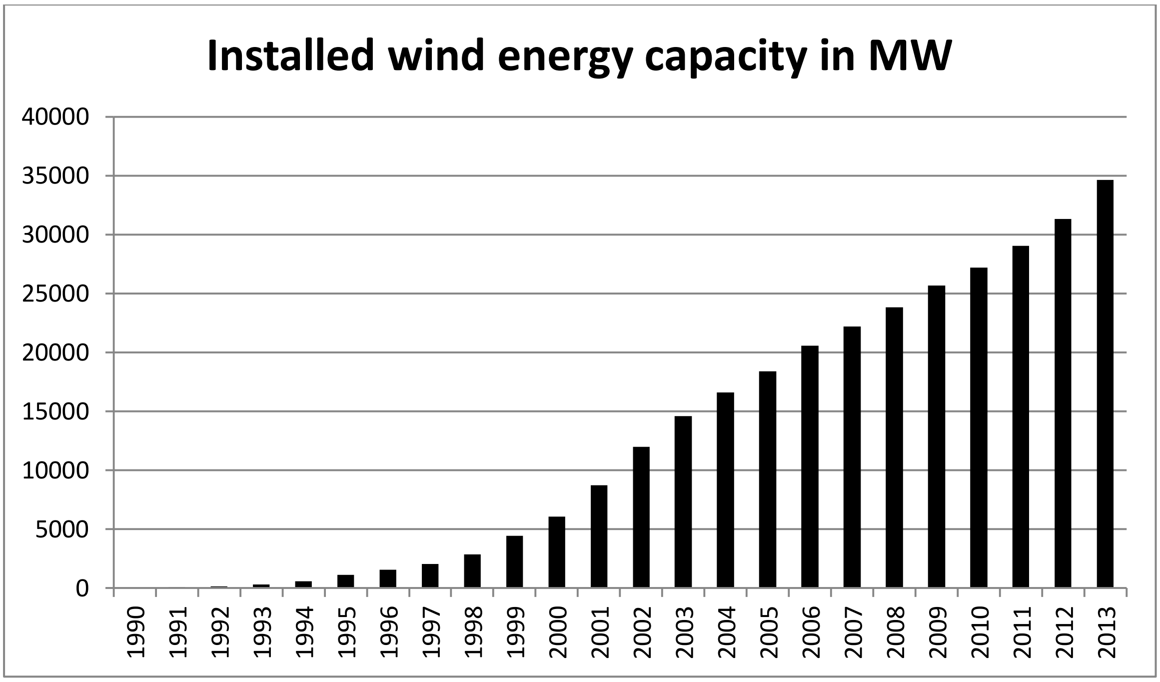

Figure 2: Installed wind energy capacity in Germany, in MW. Data from IEA, 2014.

The German onshore wind energy industry has been very much dominated by one wind energy firm, that has about 60% of the market shares: Enercon. Enercon operates only onshore, which sets it apart from its rivals. Enercon is a German wind turbine manufacturing firm founded in 1984. Enercon began with manufacturing small gearbox turbines, but shifted to gearless turbines in 1992. Enercon today has installation of over 18,000 turbines worldwide. Enercon is Germany's most important and most established wind energy firmhaving been operating for over 25 years (Urban et al, 2014). Enercon, and partly other German wind energy firms, have shaped a distinct wind energy innovation path, as the interviewees report. This innovation path focuses on high-quality, high-cost, large wind turbines predominantly using the Direct Drive in place of gears and mainly operating onshore. Enercon is well known for being the innovator that developed the Direct Drive, a gearless technology, as our interviewees reveal. The advantage of the Direct Drive is that it is more efficient and has better reliability over the entire lifetime of a wind turbine compared to gears, but the service and maintenance is more complicated compared to gears. Enercon uses an electromagnetic Direct Drive. The innovation of Enercon is based both on its innovation in wind energy technology and its innovative and very specialised business model. These insights were gained from interviewees from business and academia.

Enercon has a unique business model, which was emphasised by many interviewees. Enercon does not only sell wind turbines as other firms do, but it sells "the availability of energy" (Interview with wind energy expert, 2012). The firm operates its own wind farms, does the complete service, operation and maintenance, acts as its own insurer and component supplier, and sells the entire "wind package" (Enercon, 2012). A business model that increases the reliability of wind turbines to increase maximum financial incentives from the feed-in-tariff responds to the financial environment created by government policies.

Another feature of Enercon can be linked to the feed-in-tariffs that indirectly encourages the up-scaling of turbine sizes, outputs and projects. In 2007 Enercon launched its E-126 7.58 MW onshore turbine, which was the world's largest wind turbine until 2014 when Vestas launched its 8 MW offshore turbine. Enercon has recently focused more on developing larger turbines in the multi-megawatt segment for onshore use and the firm currently conducts R&D for turbines of up to 10MW (in addition to repowering of older wind farms and building lower wind speed turbines for less windy regions in Southern Germany). The decision to up-scale turbines to a 7.58 MW scale and to explore options for offshore wind can be linked to the structure of the financial incentives under the feed-in-tariff and the government's agenda to up-scale electric output by up-scaling turbines and projects. This means a path dependency towards larger wind turbines, mainly offshore and a lock-in with regards to smaller, decentralised turbines.

Other important onshore wind energy firms are Danish firms Vestas, REpower, Nordex, Siemens and Vensys. Danish firm Vestas has a market share of about 20% in Germany, operates both onshore and offshore and uses gear-driven turbine technology. Wind energy firm REpower has a market share of about 10% and operates both onshore and offshore. REpower was acquired by Indian firm Suzlon in 2007 (Lema et al, 2014). Nordex has a market share of about 4% and operates both onshore and offshore. Other important players are Siemens, which is a German firm, but has its main production facilities in Denmark. It operates both onshore and offshore and has recently switched from gears to gear-less direct drive technology. Finally, Vensys is another important player, both onshore and offshore. The firm was acquired by Chinese firm Goldwind in 2008 and is also operating a direct drive technology (Lema et al, 2014)..

3.3 Offshore

The higher feed-in-tariffs in the first years of a wind farm have attracted much investment in offshore wind. Nevertheless interviewees from energy firms, academia and government report that, offshore wind operations in Germany are costly and risky compared to the onshore sector. The world natural heritage and the national park of the German Wadden Sea have created natural restrictions on offshore developments along Germany's relatively short North Sea coastline. These restrictions mean that offshore wind farms have to be far off the coastline implying high investments and risks, technological and logistical challenges and also challenges in terms of connecting the offshore farms with the national grid system. Also, in contrary to other leading offshore countries, such as Denmark, the offshore waters in Germany are deep, rough and difficult to manage, as the interviewees report This has meant dependence on large multi-national utility companies such as E.ON and Vattenfall to be able to stem the large investment sums and to co-ordinate the growing complexity of building and maintaining the wind farms.

Vattenfall's Dan Tysk operates in even deeper waters (70 km offshore) and with even rougher weather conditions. In total 7 more offshore wind farms are being planned and licensed in Germany in 2013 (Interview with energy firm representative, 2013). The characteristics of the German offshore boom are partly comparable to how the onshore industry grew, but more drastic and within shorter time frames: rapid up-scaling of turbine sizes, capacities, projects and investments. German offshore farms therefore go bigger and further in a rapid pace. The constant up-scaling and the move offshore have increased the need for larger investments into both offshore wind farms and grids. Multi-national corporations such as Vattenfall, E.ON, GE and Siemens have become an integral part of the German wind industry due to their large-scale funding and involvement in offshore projects such as Alpha Ventus, Dan Tysk, Riffgat and others. These large corporations are changing the scale and pace of the German wind industry, particularly offshore, as representatives from energy firms and academia report. In a sense, Germany has become a financial and technological laboratory for offshore wind energy: this is due to the rapid development of offshore wind energy with larger turbines, which have often not been tested or installed elsewhere, and installations further out in the sea. These risks and large investments are not only covered by feed-in tariffs, but also by the higher energy prices for the consumer.

3.4. The North vs the South: challenging the grid

Wind energy resources are unequally distributed in Germany. Most of the installed capacity is in Northern Germany, close to the coast, where wind speeds are highest. The following Northern federal states had the highest share of installed capacity in 2012: Lower Saxony (7,039 MW), Berlin / Brandenburg (4,600 MW), Saxony Anhalt (3,642 MW), Schleswig Holstein (3,271 MW) and North Rhine-Westphalia (3,070 MW) (BWE, 2012). Lower Saxony, the home of Enercon, has by far the highest installed wind energy capacity (BWE, 2012). Installed wind energy capacity in the Southern federal states is small, but increasing in recent years, particularly in Baden-Wurttemberg and Bavaria, often in areas with low mountain ranges (BWE, 2012) The windy areas in Northern Germany become increasingly saturated with wind farms, whereas there is still space for wind turbine developments in Southern Germany. However wind speeds are much lower in the South, therefore different turbines have to be used. Several firms, including Enercon and Vensys, have developed specific turbines for low wind speeds as a response to this challenge, as the wind firm interviewees reveal.

A second challenge is the imbalance in electricity demand between the Southern German federal states which have low wind resources, but high electricity demand and the Northern German federal states such as Lower Saxony and Schleswig-Holstein which have strong winds, low electricity demand and an over-supply of wind energy. The Northern federal states request the improvement and expansion of grid infrastructure from North to South to facilitate long-distance electricity transport. The Southern federal states however prefer to build more wind turbines in the South instead of importing wind energy from the North, despite low wind speeds.

All interviewees agree that the aging and inadequate grid infrastructure poses risks to the German wind energy innovation path. The German wind energy industry currently faces challenges in accessing and expanding the grid. Many interviewees argue that there have been no adequate grid investments in the last decades. Some interviewees mention that in Schleswig-Holstein, 40% of the electricity comes from wind energy, but when wind speeds are high turbines have to be switched off as the grid is too old and cannot cope with the excess electricity capacity. There is also the practical problem of connecting the wind farms to the grid, which is complicated for offshore wind farms. The grid provider will only establish a connection when it is guaranteed that the wind farm will be successfully completed. For the wind farm providers this is a catch 22 as they need confirmation from the grid provider before being able to secure investments from investors for the offshore wind farm. A new legislation on Haftungsausschluss (exemption from liability) requires that the risk is shared between the wind farm operator, the grid provider, the public / tax payer and the consumers. Hence some of the burden of offshore wind farms is at the expense of the tax payers/consumers.

Some interviewees from energy firms and academia argue it is the responsibility of the government to push forward the grid integration and the grid expansion. They argue that government authorities need to regulate the actors more tightly and force grid operators such as Tennet to invest in expanding the grid and making it compatible with offshore wind energy. Some interviewees point out that large offshore projects such as Alpha Ventus have been delayed for 2 years due to grid connection issues (Interviews with wind energy experts, 2013). There is also an agreement that federal states need to be involved so that electricity transport from the North to the South will be smooth and efficient. A challenge is at the moment that Southern federal states want to become more independent and increase their own wind energy capacity. In Southern Germany turbines are being built in low wind speed areas which could decrease the demand for wind energy from the North.

4 Discussions

The research finds that while the share of wind energy has increased rapidly over time, the feed-in-tariff and other low carbon policies and incentives have not been sufficient to achieve a socio-technical regime transition in Germany yet.

We suggest that we have reached a feed-in tariff lock-in which has led to path dependency towards up-scaling of wind energy turbines and projects. It has led to larger wind energy turbines and projects onshore as well as more financially risky off-shore projects since these tend to produce larger outcomes per megawatt, hence receive more subsidies. This finding is supported by other studies that argue that small wind energy turbines in Germany have received little attention and fewer subsidies through the feed-in-tariff and the EEG (BWE, 2010). The lock-in could here be described as focusing on innovation in large turbine design only and on up-scaling energy generation output beyond having the actual financial, technical and organisational capacity to transmit and distribute the electricity in an efficient way. For enabling the German Energiewende, improvements in the grid system are crucial, while the upscaling of turbine sizes, capacities and projects is desirable, but not pivotal. The Energiewende can therefore not be fully accomplished if the current formulation of the feed-in-tariff creates a technological lock-in and a path dependency that focuses on innovation that is important (larger wind turbine sizes, capacities, projects), but not game-changing (as would be a state-of-the-art grid that would enable efficient long-distance transport of wind energy from North to South, including from offshore wind farm).

There is no specific funding that is available for grid expansion, improvement and integration (which is crucial for offshore wind farms). The feed-in-tariff is aimed solely at increasing wind-based electricity output. Payments are made per kWh of generated wind-based electricity. The financial incentives are not focussing on transmission and distribution of wind-based electricity. The large majority of interviewees suggested that the main bottleneck for the Energiewende is the out-dated and under-funded grid, not the size or state of current wind energy technology in Germany. The empirical research revealed that grid operators and utilities are not incentivised to invest in the grids, while the government is also not investing. This inaction and non-responsibility on both sides, which is partly caused by inadequate policy, legal and financial instruments for grid improvements and maintenance, is a main barrier to the Energiewende.

The main issue is that North Germany, including the offshore wind farms, produces more wind energy than the aging grid system can handle. Hence, the electricity from the North is not distributed efficiently to the South where the demand for electricity is high. The plans to build a long-distance electricity link (Stromtrasse**)** between North Germany (Niedersachsen, Schleswig-Holstein) and South Germany (Bayern, Baden-Wurttemberg, Hessen) have been met with an enormous public and political resistance. The federal state of Bayern has requested a moratorium on the project. Further, many civil society organisations are planning protests against the project.

Alternatives to use wind energy more efficiently through smart grids, citizen's networks or electro-mobility have not been sufficiently pursued in Germany. For example, while purchase subsidies for electric vehicles exist in France and China (Altenburg and Pegels, 2012), they do not exist in Germany. This means that the feed-in tariff creates its own lock-in and path dependency which have excluded other innovation paths for low carbon development in general and wind energy in specific. The German feed-in tariff has become the lifeline for an ever expansive production of new wind energy capacity, a sector thriving due to subsidies of the state while there is a shrinking political will to upkeep the costly feed-in tariff system in its current form. The previous coalition government (CDU/CSU and FDP) and the current coalition government (CDU and SPD) have discussed ways to reduce the feed-in-tariff.The discussion has been either about the appropriate level for the feed-in tariff or whether there should be a feed-in tariff at all. There has been little discussion or planning for alternatives and more sustainable funding policies that shares the costs of the energy transition more equally such as through taxesThe EFI report confirms that the EEG and the feed-in-tariff have led to an expansion of renewable energy in Germany, but doubts whether innovation in renewables has been sufficiently stimulated through the schemes. Their radical, contentious and contested recommendation is to abolish the feed-in-tariff altogether (EFI:2014:2). This is however strongly contested by wind energy firms that are arguing that their firms and the entire wind energy sector would go bankrupt if the feed-in-tariff were to be abolished or significantly reduced. The question is however whether subsidies for wind energy in Germany need to be formulated more sustainably so that innovation is encouraged and firms will flourish without excessive costs to the consumers.

Current German wind energy policy has creates two financial dilemmas: First, it has pushed up energy costs for consumers through the feed-in-tariff, second it has lowered energy costs for energy-intensive industries through feed-in-tariff exemptions. This has created an unequal burden for consumers. This means we cannot observe a comprehensive energy transition towards a low carbon economy but what we see is an integration of renewable energy into an existing industrial economy. The renewable energy policy protects the interests of wind energy firms, utilities corporations and large energy-intensive industries.

There is a lock-in towards increasing production of wind energy and far less towards the consumption side of the Energiewende. The wholesale price of electricity has in fact been significantly reduced due to the increasing share of renewable energy. Energy providers and utilities buy the cheap electricity on wholesale markets and sell it at expensive consumer prices; despite a reduction of the wholesale electricity prices. Large industries are receiving preferential treatment as they are exempt from the tariff. Hence, industries, energy providers and utilities are making large profits from the feed-in-tariff, while individual customers and households have to pay increasing electricity bills. These bills are however not increasing because of a higher share of renewables in the energy mix, but because of corporate greed and poorly designed energy policy (IWR, 2014).One could therefore argue that wind energy has been a niche innovation that was creating novelty, challenged an existing regime and opened up an opportunity for transformative change. On the other side one could also argue that niche innovation could partially change or be incorporated within an existing socio-technical regime without undermining either the socio-technical regime or the socio-technical landscape. “At the meso-level of the “socio-technical regime”, socio-technical configurations are temporarily stabilized and supported by a rule set or “grammar” that structures the socio-technical co-evolution process” (Rohracher and Späth: 2012:465).

Of interest is therefore to create a deeper understanding of how energy transitions can be only partial while still stabilize interdependencies and path dependencies of previous energy systems. If particular innovation niches are incorporated into a socio-technical regime this could have stabilizing effects and create new lock-ins and self-reinforcing mechanisms which could help explain why the German wind-led Energiewende has not been more successful and why it is both constantly questioned and still very much resistant to change. Instead of making a transition from one socio-technical system to another, qualitatively different one, we can see a slow evolutionary development which could be considered more of a hybrid system than a new system. Table 3 shows how a lock-in and path dependency towards an ‘incomplete’ Energiewende has been created in Germany which does not achieve its full potential at the moment.

Lock-in and path dependency of an incomplete energy transition	
Feed-in-tariff favouring up-scaling and offshore	Innovation and investments in large turbines and projects at the expense of investments in grids and other innovation (e.g. low wind speed turbines, smaller turbines, systems integration with electric vehicles etc)
Aging, under-performing grid	Lacking grid expansion for onshore and offshore, lacking grid integration for offshore
Full potential for energy transition not achieved	Offshore wind energy growth restricted by grid bottlenecks, North-South long-distance transport of electricity restricted by grid bottlenecks, innovation and investments in other core technology and deployment areas neglected due to focus on up-scaling and

	offshore

Table 3: Lock-in and path dependency

5. Conclusions and policy implications

This article concludes that the feed-in-tariff's implicit drive for up-scaling wind turbine sizes and projects diverted attention and funding away from other forms of innovation such as in grid systems. This has led to a socio-technical system characterised by inertia and lock-in. This means that the German state per se has difficulties creating an overall stimulating innovation system for renewable energy. At the same time the inter-dependency between the feed-in-tariff and the wind energy industry has to be stressed. The wind energy industry argues that wind firms are highly dependent on the feed-in-tariff to succeed financially. At the same time, the feed-in-tariff would maybe not exist any longer if the wind energy industry lobby had been weaker. However, this is partly due to the absence of other successful mechanisms for fostering wind energy innovation and technology in Germany. The dilemma is that while the feed-in tariff has been successful in increasing wind energy capacity, it relies on the individual consumers to pay while large energy-intensive firms and the government are not shouldering the economic burden it creates. Apart from its sinking popularity among voters and among some political parities the feed-in tariff has created a booming industry entirely dependent on consumers' willingness to put up with risings costs for energy while the wholesale energy prices drop. The state has shown little interest in using other financial mechanisms or policies to support wind energy innovation and an overall energy transition. The feed-in-tariff exemptions for energy-intensive industries (which are essentially subsidies) show that the German government does not venture into a full energy transition but merely integrates wind energy into an already existing (and energy intensive) industrial socio-technical regime.

Based on empirical research, we assessed the relationship between the feed-in-tariff and technological lock-in for wind energy innovation in Germany. The key policy recommendation we suggest is that mechanisms for fostering wind energy innovation and technology in Germany should go beyond focusing on feed-in-tariffs only for up-scaling of turbines and core technologies and should aim to promote and finance deployment technologies and systems integration technologies, most importantly with regards to improving the aging grid system and enhancing grid integration. It is crucial to improve and upgrade the grid system in Germany as it is one of the major bottlenecks that restrict the growth of the national wind energy market, particularly offshore. Grid-specific policy and financial incentives could be complementary to the feed-in-tariff.

German wind energy policy needs to move beyond the singular feed-in-tariff lock-in thinking and develop multiple, new, innovative financing and support incentives for promoting wind energy innovation and the appropriate grid infrastructure in the future. German low carbon policy and incentives have therefore created a slightly modified socio-technical regime that is rather similar to the earlier 'fossil fuel dominant' socio-technical regime. However for a comprehensive, long-term Energiewende more radical transformations of socio-technical regimes are needed. It is also important that the consumer will not shoulder the main burden of the energy transition but that also industries and the state contribute to a larger extent.

Future research should investigate first how to reform the feed-in-tariff in a way that is more consumer-friendly and more effective in fostering systems innovation. Second, future research should contribute to suggesting new financial and policy incentives that promote innovation in wind energy and grid systems. The ultimate goal should be to overcome the current bottlenecks and achieving a successful energy transition.

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