Research Policy 43 (2014) 1422–1441

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Compulsive policy-making—The evolution of the German feed-in tariff system for solar photovoltaic power

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ARTICLE INFO

Article history:
Received 29 January 2013
Received in revised form 29 January 2014
Accepted 30 January 2014
Available online 18 March 2014

Keywords:
Sustainability transitions
Innovation system
Innovation policy
Policy learning
Feed-in tariff
Solar photovoltaic power

ABSTRACT

In recent years, policy approaches that build upon the notion of innovation systems have enjoyed increasing attention in science, technology and innovation policy. But while the usefulness of systemic thinking in policy-making has been demonstrated in a large number of empirical settings, we still lack a detailed understanding of the dynamics at play when policy makers address systemic problems. In this paper, we show how complex interdependencies and the uncertain nature of technological change shape the process of targeted policy interventions in socio-technical systems. Toward this end we analyzed the evolution of the German feed-in tariff (FIT) system for solar photovoltaic power, a highly effective and widely copied policy instrument targeted at fostering the diffusion and development of renewable energy technologies. We find that the policy has been subject to a considerable amount of changes, many of which are the result of policy makers addressing specific system issues and bottlenecks. Interestingly, however, often these issues themselves were driven by unforeseen technological developments induced by previous policy interventions. We argue that the pattern of policy serving as both a solution to and a driver of technological bottlenecks shows strong similarities with what Rosenberg (1969) called 'compulsive sequences' in the development of technical systems. By shedding more light on how the characteristics of socio-technical systems affect policy interventions, our framework represents a first step toward more closely integrating the literature on innovation systems with the work on policy learning.

1. Introduction

Environmental degradation, resource depletion and climate change are pressing societal problems that call for a redirection of economic growth toward a more environmentally sustainable pathway (UNEP, 2011). Such a 'sustainability transition' is likely to require the development and use of fundamentally new products, processes and services (Markard et al., 2012; Smith et al., 2010). Whereas this implies an altered behavior of a wide range of actors, such as corporations and private consumers, there is a broad consensus that public policy will have to play an important part in facilitating the transition. Considering the urgency of problems, it is argued that regulators should guide and accelerate the process of change by altering the institutional framework, breaking path dependencies and fostering the emergence of innovative, more environmentally benign technologies (Jacobsson and Bergek, 2011; Unruh, 2002).

In recent years, innovation scholars have strongly advanced our understanding of the role that public policy can play in fostering the transition toward sustainability. For example, the literature on innovation systems has identified so-called 'system failures' or 'system problems' that hinder the development and diffusion of new technologies (e.g., Klein Woolthuis et al., 2005; Negro et al., 2012) and has suggested a number of 'functions' or 'key processes' policy makers should support to overcome these issues (e.g., Bergek et al., 2008; Edquist, 2011; Hekkert et al., 2007). The practice of systems thinking has found increasing use in policy circles in recent years (Wieczorek and Hekkert, 2012). Up to this point, however, we lack a detailed understanding of how policy responses emerge from systemic imbalances and how they co-evolve with the system that policy makers intervene in Kuhlmann et al. (2010). The literature emphasizes the complex nature of innovation systems, with many interdependent actors and institutions (Faber and Alkemade, 2011). Yet, it remains unclear how this affects policy maker's ability to purposefully induce technological change. Studies in the field of policy sciences have stressed the emergent nature of policy processes and investigated factors that facilitate policy learning (Lindblom, 1959). However, when analyzing the drivers of policy evolution, typically these studies have focused on the political system as the intervening entity, rather than technological

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http://dx.doi.org/10.1016/j.respol.2014.01.014

change and the characteristics of the system to be intervened in.

To gain more insights into the dynamics that result when policy makers try to purposefully intervene in socio-technical systems, in this paper we address the question of *how the complex dynamics of innovation systems shape the process of policy interventions targeted at inducing technological change.* Toward this end, we study the evolution of the widely copied German feed-in tariff (FIT) system for solar photovoltaic (PV) power as an instrument that has been highly effective in driving the development and diffusion of PV technology. In this context, we analyzed a large number of archival documents pertaining to the policy process such as legislative texts, protocols of parliamentary debates, expert studies and press articles. This archival analysis was complemented by interviews with policymakers and designated PV industry experts as actors in and observers of the policy process.

We show that the German FIT for PV has evolved in a highly iterative way with policy makers adjusting the policy design over time. Some of the policy changes were due to politics and policy makers correcting flaws in previously implemented legislations. More interestingly, however, we find that besides these factors the evolution of the German FIT for PV was strongly driven by – often unforeseen – developments in the technological sphere. Policy makers implemented policies that addressed particularly prevalent 'system failures' or 'system issues' hindering the development and diffusion of solar PV in Germany. Although these policy measures contributed to eliminating specific issues, we find that, by inducing unexpected technological developments, policy simultaneously contributed to the emergence of new issues which needed to be addressed in subsequent steps. We argue that understanding policy interventions in socio-technical systems in analogy to what Rosenberg (1969) described as 'compulsive sequences' of innovation, may help inform future interventions in innovation systems. The framework of 'compulsive policy-making' we propose goes beyond more generic frameworks of policy learning (e.g., Bennett and Howlett, 1992; Lindblom, 1959) by stressing the role of technological change and complex interdependencies in socio-technical systems as a driver of policy change.

The remainder of this paper is structured as follows: Section 2 presents a brief overview of the work on innovation systems and discusses potential mechanisms shaping policy dynamics suggested in the literature. Research case and method are outlined in Sections 3 and 4. Section 5 describes the evolution of the German FIT system for PV, followed by a discussion of the underlying technological dynamics and the theoretical framework we derive in Section 6. We conclude with a brief description of the study's limitations, suggestions for future research and a summary of the main contributions.

2. Theoretical perspective

2.1. Innovation systems analysis as a means to inform policy interventions

In the last two decades, the concept of innovation systems has gained increasing importance in informing policy interventions in the field of science, technology and innovation policy (Edquist, 2011; Smits and Kuhlmann, 2004; van Mierlo et al., 2010). It builds upon the idea that the development, diffusion and use of technologies results from the interplay of a large number of actors (e.g., firms, policy makers), networks (formal and informal), technologies (e.g., knowledge and artifacts) and institutions (e.g., norms, values or regulations) within a socio-technical system (Carlsson and Stankiewicz, 1991; Edquist et al., 2005). To foster technological change, the literature suggests carefully analyzing the socio-technical system to identify so-called 'system failures' or 'system problems' as the focus of policy interventions. Previous work has clustered failures into categories, such as 'institutional', 'network' or 'capability' failures, and suggested systematic procedures for their identification (Carlsson and Jacobsson, 1997; Klein Woolthuis et al., 2005; Negro et al., 2012; Smith, 1999). In the latter context, a number of 'functions', 'key processes' or 'key activities' have been proposed that policy makers should focus on when searching for systemic failures that may prevent technology development and diffusion (Bergek et al., 2008; Edquist, 2011; Hekkert et al., 2007). It is suggested that, to devise technology-specific policies, policy makers should measure the extent to which different processes are present within an innovation system, detect mechanisms inducing or blocking these processes and implement policy measures to remove potential system bottlenecks (Bergek et al., 2008; Wieczorek and Hekkert, 2012).[1]

The analysis of innovation systems has proven a powerful heuristic for identifying starting points of policy interventions and explaining the success or failure of technology development and diffusion. However, since the focus of innovation system studies is on analyzing the socio-technical system as a whole rather than the details of policy processes, we lack a sufficient knowledge about how policy responses emerge from systemic imbalances and how they co-evolve with the system that policy makers intervene in Kuhlmann et al. (2010). While the innovation systems literature itself does not intend to provide a detailed explanation of the policy process, a better understanding of the link between system failures and policy-making could be fruitful as it may help (a) uncover the underlying dynamics of innovation system evolution and (b) improve the practical relevance of policy recommendations made. Therefore, in the following we take a closer look at two mechanisms affecting the dynamics of policy interventions in innovation systems that have been discussed in the literature.

2.2. Potential mechanisms shaping the dynamics of policy interventions in innovation systems

As one important mechanism shaping the dynamics of policy interventions in innovation systems, early studies in the field have investigated the role of *politics and interest* (Jacobsson and Bergek, 2004; Jacobsson and Lauber, 2006; Jacobsson et al., 2004). In line with the literature on the politics of sustainability transitions it has been pointed out that the transformation of socio-technical systems is an inherently political process influenced by mindsets, framing and power struggles (Kern, 2011; Meadowcroft, 2009, 2011; Scrase and Smith, 2009). Politicians anchored in an existing regime are unlikely to show strong support for emerging technologies and may resist related political initiatives (Kern and Smith, 2008). Moreover, policy makers may hold differing opinions on what constitute the most important system failures and how to remove them (Meadowcroft, 2009).

A second mechanism that is likely to shape the dynamics of policy interventions aimed at removing specific system failures is *limited capacity and foresight of policy makers*. Even if there is a political consensus regarding the goals and means of policy-making, the inherent complexity of socio-technical systems may limit the degree to which consequences of policy interventions can be accurately foreseen (Faber and Alkemade, 2011). As expressed in Lindblom's (1959) 'science of muddling through', policy makers

[1] The logic of identifying and removing system bottlenecks appears similar to 'Liebig's law of the minimum' in agricultural science. According to Liebig's law, which was originally developed by Carl Sprengel in the early 19th century, the performance of a system consisting of a number of interdependent elements is limited by the scarcest resource.

generally possess a limited capacity to enlist and evaluate all possible policy measures and outcomes. As a result, they therefore have to make use of a try-and-error approach to partially achieve their goals and subsequently adjust actions based on the experience they have gained (Forester, 1984; Lindblom, 1959, 1979). The resulting process of policy learning has been an important subject of study in the literature on policy science (Bennett and Howlett, 1992; May, 1992; Sanderson, 2002). In this context, different forms of policy learning have been identified and investigated with regard to their antecedents (Bennett and Howlett, 1992).

The literature on policy learning has generated valuable insights into the exact mechanisms through which policy makers learn. Yet, in this stream of literature the question of what shapes the policy process has generally been answered by looking at the characteristics of governing bodies rather than the properties of the socio-technical system in which they intervene. In particular, iterations in policy processes are usually assumed to emerge due to the inability of policy makers to design appropriate policies. While the political system decisively affects policy learning, it seems promising to take a closer look at how the process of policy learning is affected by the dynamics of and interdependencies within the socio-technical system that policy makers intend to change. Policy learning may play a particularly important role when policy makers try to purposefully induce technological change which has been shown to evolve in a non-linear, unpredictable way. In line with this, the literature on innovation systems stresses that these systems consist of a large number of structural elements that interact through various channels, implying that the outcome of policy measures may be hard to anticipate. Yet, while it has been acknowledged that policy interventions in innovation systems may have unforeseen effects (Bergek and Jacobsson, 2003; Bergek et al., 2008), we currently lack a sufficient understanding of how the complexity of socio-technical systems might relate to processes of policy learning. At present, the literature predominantly assumes positive interdependencies between elements of innovation systems. It is suggested that removing specific system failures leads to ‘virtuous cycles’ (Bergek and Jacobsson, 2003; Hekkert and Negro, 2009; Negro and Hekkert, 2008), ‘cumulative causation’ (Hekkert et al., 2007; Suurs and Hekkert, 2009) and the emergence of ‘positive externalities’ (Bergek et al., 2008). Positive interdependencies have been empirically demonstrated in several case studies (e.g., Suurs and Hekkert, 2009). Yet, one could think of cases where removing system failures may not affect all other system elements in a positive way. For example, fostering demand to overcome ‘market failures’ can lead to the scaling-up of production and lower product costs, thereby raising the barriers to market entry for entrepreneurs (Hoppmann et al., 2013). As a result, complex interdependencies between the elements of an innovation system may lead to situations where policy interventions unexpectedly enhance existing or generate new system failures, requiring policy makers to learn. Considering this possibility, in this paper we focus on the question *how the complex dynamics of socio-technical systems shape the process of policy interventions targeted at inducing technological change.* Based on an in-depth case study of a policy intervention that aims at addressing specific failures in an innovation system, we derive a process model that integrates the different mechanisms presented in this section.

3. Research case

To gain more insights into the dynamics that result when policy makers try to address failures in socio-technical systems, we study the evolution of the widely copied German feed-in tariff (FIT) system for solar photovoltaic (PV) power from 1991 to early 2012. FITs, which grant power producers a fixed price per unit of electricity, are generally implemented to foster technological innovation and diffusion of renewable energy technologies (Dewald and Truffer, 2011).[2] Studying the evolution of this instrument therefore allows us to better understand the dynamics that result when policy makers try to purposefully intervene in an innovation system to enhance its performance.

Germany is a suitable country for the analysis since throughout the period of analysis public and political support in Germany for renewables was rather high.[3] Compared to other countries, there has been a stronger political consensus that increasing renewable energy supply is desirable, implying that political struggles revolved not so much around the goals (i.e., what to achieve) but the means (i.e., how to achieve them).[4] Partisan politics thus played a smaller role than in other contexts. Furthermore, we chose Germany as a country since the FIT system has been very effective in increasing the share of renewable power in the electricity mix, and has served as a blueprint for FIT schemes in other countries (Ringel, 2006). Of the more than 60 countries that have introduced a FIT, Germany was the second country to adopt this instrument and up to this point has shown a remarkable continuity in its operation (REN21, 2011). The long time horizon over which developments in the legislation can be tracked was considered advantageous for obtaining robust results.

We further confine our analysis to the case of solar photovoltaic power. While PV bears a large physical potential for the generation of clean electricity, its levelized costs of electricity (LCOE) are still well above those for fuel-based electricity sources. As a result, PV currently is strongly dependent on policy support, implying a high visibility of policy effects and policy dynamics in the socio-technical system (Peters et al., 2012). The good opportunity to observe policy dynamics in operation militates in favor of choosing PV as a unit of analysis.[5]

Finally, we set the temporal boundaries of our research to the time from 1991 to the beginning of 2012. We constrain our analysis to the German Renewable Energy Sources Act of 2000 and its subsequent amendments because the first version of the German FIT, the so-called ‘Stromeinspeisungsgesetz’ of 1990, had almost no direct effect on PV in Germany. The FIT of 2000 has received much attention in the years after its introduction (e.g., Jacobsson and Lauber, 2006; Jacobsson et al., 2004; Lauber and Mez, 2004), but the significant changes in the FIT scheme for PV, especially since 2007, have not yet been comprehensively documented and studied in the academic literature.

4. Method

We employed qualitative case study research since this methodology allows us to obtain an in-depth understanding of the policy dynamics and the mechanisms driving them over time (Eisenhardt and Graebner, 2007; Yin, 2009).

[2] As will be seen in Section 5, motivations to implement a FIT often go beyond the mere development and diffusion of renewable energies. For example, the appendix of the German Renewable Sources Act 2000 lists, among others, the creation of industries and jobs, reduction of import dependence of fossil fuels, as goals.

[3] We focus on policies and market formation in Germany. Still, we include developments in the innovation system for PV outside of Germany in our analysis whenever they have important effects on the socio-technical system in that country.

[4] It should be noted that, especially at the end of the 1980s renewables faced significant headwind from the CDU/FDP leadership in the German Bundestag (Jacobsson and Lauber, 2005). Moreover, there remains considerable disagreement regarding the rate at which renewable energy technologies should be deployed.

[5] While we define PV as our unit of analysis, the fact that this technology is embedded in a larger technological system, encompassing for example the electricity grid, makes an isolated consideration of PV impossible. In our analysis, we therefore include developments in and effects on adjacent technologies whenever necessary.

Table 1
Overview of analyzed archival documents.

Category	No. of documents
Legislative texts pertaining to the German Renewable Energy Sources Act	8
Protocols of sessions of the German Bundestag	110
Legislative drafts and petitions	81
Protocols and reports of expert committees	104
Briefings by the German government (incl. EEG experience reports)	72
Protocols of parliamentary question times (incl. answers)	67
Minor interpellations directed to the German government (incl. answers)	88
Major interpellations directed to the German government (incl. answers)	23
Issues of industry magazine “Photon”	166
External expert studies	6
Sum	725

For our analysis we drew on two main data sources. First, to obtain a broad understanding of the contextual factors we conducted a series of semi-structured interviews with 21 designated PV industry experts.[6] Experts were sampled in a way that ensured that they covered different positions in the industry and that they provided both insiders' and outsiders' perspectives on the policy-making process. Of the experts interviewed, 7 were directly involved in the legal process, e.g., by being members of the German national parliament, working in the ministry of environment or serving as experts for expert committees. Among those interviewees not directly participating in the political process were investors, project developers, representatives of firms producing PV modules and manufacturing equipment, scientists and market analysts.

Second, as the primary source of information, we conducted a comprehensive analysis of more than 700 archival documents describing both the process and outcome of policy-making for the German FIT system for PV. We began by collecting the legislative texts pertaining to the German Renewable Energy Sources Act (EEG) with its 8 amendments. These documents served as a data basis to describe how the policy as the *legislative basis* related to the German FIT has changed over time. To obtain an in-depth understanding of the *policy process* that led to the changes in legislation, we then searched the archive of the German National Parliament ('Bundestag') for documents containing the keywords 'solar', 'solar energy', 'solar power', 'sun power' and 'photovoltaic' (in German).[7] This search yielded 715 documents of which 170 were deleted because they were considered of little value for our analysis. Finally, to understand the *effects of the policy on the broader socio-technical system*, we gathered additional quantitative and qualitative data on annual and cumulative PV deployment, industry development, jobs, annual and cumulative costs as well as PV system prices in Germany. In this context, among other sources, we screened 6 additional expert studies dealing with the German FIT for PV as well as 166 issues of the leading industry magazine “Photon” from 1996 to 2011. An overview of the archival documents we analyzed as part of our study is given in Table 1. Moreover, Table A.1 in the appendix contains a list of the 57 most important documents in chronological order.

To derive theoretical insights from our data sources, the interview transcripts and archival documents were analyzed using qualitative content analysis. Following the logic of innovation system analyses, we first used ATLAS.ti to code the documents describing the policy process to identify prevalent issues, i.e., system failures and other drivers mentioned as a rationale for policy implementation in the policy discourse. Using a bottom-up, iterative coding procedure, we identified a total of 2354 text elements which we grouped into 15 issue categories (see Table A.2 in the appendix for an overview of the categories and their frequency of occurrence in the documents over time). In a second step, we then applied pattern matching to establish relationships between the identified issues, implemented policy measures and the observed changes in the socio-technical system (Yin, 2009). Triangulation of our various data sources allowed us to uncover for each point in time whether and why policy makers were acting upon prevalent issues in the socio-technical system, how the policy interventions resulted in changes in the socio-technical system and how these system changes, in turn, affected the issues discussed in the further political discourse. Taken together, this analysis provided insights on the relevance of system complexity, i.e., the extent to which developments in the system and consequences of policy interventions were intended or foreseen. By analyzing the rhetoric and action of the political actors in detail we could further control for the role of politics.

5. Evolution of the German FIT system for PV

In the following, we describe the evolution of the German FIT system for PV from 2000 to the beginning of 2012. For the sake of readability, we cluster the development of the instrument into four phases during each of which policy makers focused on specific changes in policy design. For each of the phases we first describe the main issues in the socio-technical system. We then discuss the implemented policy changes targeting these issues as well as the effects these had on the socio-technical system. During our description, we use the codes D1–D54 to reference the original policy documents listed in Table A.1 in the appendix. An overview of the four phases, displaying the respective system issues, implemented policy changes and effects on the socio-technical system is given in Table 2. Supporting the information in Table 2, Table 3 shows how the relative importance of issues in each of the phases has evolved over time.

5.1. *Phase 1: establishing a sufficient financial incentive (until 2000)*

Prior to the year 2000, development and deployment of PV technologies in Germany were not driven by national feed-in tariffs but a mix of direct R&D funding, smaller local initiatives and two large demonstration programs, the 1000 and the 100,000 roofs program. In the year 1991, based on a report of a cross-party working group (the so-called 'Enquete Komission' – see document D1 in Table A.1 in the appendix), the first Feed-in Law ('Stromeinspeisungsgesetz' – D2) was established by the governing coalition consisting of the Christian Democratic (CDU) and the Liberal Democratic Party (FDP). The law was passed with strong parliamentary support in 1990 after the CDU/FPD leadership in the Bundestag had initially stopped a member's bill to create a market for renewable energies in 1989. However, this law “had no measurable effect on the use of photovoltaic power” (D7) since the remuneration at a level of 90% of

[6] Interviews lasted between 60 and 90 min and were conducted by at least two researchers to ensure the reliability of the findings.

[7] To understand the origin of the 2000 Renewable Energy Sources Act, the analysis of archival documents comprised archival data reaching back as far as 1980.

Table 2
Evolution of the German FIT System for PV from 2000 to beginning of 2012.

Phase	Prevalent issues in socio-technical system	Time of policy change	Parties in government	Changes in policy design	Effect on socio-technical system
1	• Lack of maturity and high cost of PV technology • Lack of mass market for PV • Insufficient financial incentive for power producers of PV • Market power of large utilities • Market support as chance to build PV industry and create jobs	2000	SPD and Green	• Introduction of Renewable Energy Sources Act • Technology-specific but size-independent remuneration of 51 EUR cents/kWh over 20 years • Maximum size of 5 MW for building integrated plants, 100 kW for others • Fixed degression of 5% p.a. • Ceiling for cumulative installed capacity at 350 MW • Exclusion of utilities with share of EEG electricity > 50% in overall sales from having to pay EEG apportionment ('Grünstrom-privileg')	• First boost in deployment (cumulative capacity of 186 MW installed in 2001) • No. of jobs grows slowly to 4000 in 2001 • Rise in annual PV difference costs[21] from 19 M EUR in 2001 to 37 M EUR in 2001
2	• Market support as chance to build PV industry and create jobs • Market support as chance to increase exports • High cost and rising electricity prices (problematic especially for energy-intensive industry)	2002	SPD and Green	Ceiling for cumulative installed capacity raised to 1000 MW	• Strong rise in deployment (cumulative capacity of 4170 MW installed at the end of 2007) • Reduction of PV system price from 6 EUR/Wp in 2002 to 4.3 EUR/Wp in 2008 • Strong rise in no. of jobs to 40,400 in 2007 • Rise in annual PV difference costs to 1.47 bn EUR in 2007
		2003	SPD and Green	• Reduction of EEG apportionment (0.05 EUR cents/kWh) for large electricity consumers facing international competition with a consumption > 100 GWh, electricity cost per gross value added > 20% • Removal of ceiling for cumulative installed capacity and plant size • Increase in remuneration for roof-top PV to 54.7 EUR cents/kWh	
		2004	SPD and Green	• Changes in redistribution mechanism of EEG apportionment • Adjustment of criteria for reduction of EEG apportionment for large electricity consumers to consumption > 10 GWh, electricity cost per gross value added > 15%	
3	• High cost for society and rising electricity prices • Excess remuneration and windfall profits for PV industry • Increasing competition from China • Risk of hurting domestic industry	2009	CDU and SPD	• Dynamic degression of remuneration depending on deployment (basic degression of 8–10% for 2010 ± 1 percentage point if annual installed capacity < 1000 MW or >1500 MW)[22] • Requirement to install remote control and power measurement unit for plants > 100 kW • Option of self-consumption (25.01 EUR cents/kWh) or direct marketing to third parties[23]	• Further increase in deployment (cumulative capacity of 24,678 MW installed at the end of 2011) • Slowing market growth • Rise in no. of jobs to 150,000 in 2011 • Rise in annual PV difference costs to 6.8 bn. EUR in 2011 • Strong reduction of PV system prices from 4.3 EUR/Wp in 2008 to 2.05 EUR/Wp at the end of 2011
		2010	CDU and FDP	• Basic degression for 2010 changed to between 8% to 13% depending on system size • Dynamic degression rate for 2011 raised (basic degression of 9% ± up to 4 percentage points depending on deployment in 2010) • Additional one-time reductions of remuneration by 10% (July) and 3% (October) • Reform of distribution mechanism underlying EEG apportionment	
		2011	CDU and FDP	• Adjustment of degression for 2011 by 3%, 6%, 9%, 12% or 15% depending on deployment in March to May 2011(target corridor of 2.5–2.5 GW newly installed capacity per year) • Adjustment of degression for 2012 (9% basic degr., reduction or increase dep. on deployment in 2011)	
4	• Increased power intermittency and power regulation • Risk of reduced grid stability • Lack of market integration • High cost for society and rising electricity prices	2012	CDU and FDP	• Alternative between limiting inverter power to 70% of PV plant capacity or installation of remote control for plants < 30 kW • Remuneration for self-consumption depending on system size (max. 12.36 EUR cents/kWh) • Further extension of reduction in EEG apportionment for large electricity consumers: criteria adjusted to consumption n > 1 GWh, electricity cost per gross value added > 14% • Limitation of 'Grünstromprivileg' (see Phase 1) to 2 EUR cents/kWh • Introduction of market premium as incentive for direct marketing	?

Table 3
Relative prevalence of issues in phases.

Issue Category	Relative prevalence of issue in phase			
	Phase 1: < 2000	Phase 2: 2000-2003	Phase 3: 2004-2010	Phase 4: 2011
Lack of maturity and high cost of PV technology	14%	3%	2%	1%
Lack of mass market for solar PV	11%	0%	0%	0%
Insufficient financial incentive for power producers of PV	26%	3%	0%	0%
Market power of large utilities	10%	3%	2%	0%
Market support as chance to build PV industry and create jobs	30%	38%	17%	3%
Market support as chance to increase exports	3%	13%	7%	1%
High cost for energy-intensive industry	0%	7%	4%	5%
High cost for society and rising electricity prices	3%	18%	18%	16%
Increasing competition from China	0%	0%	5%	1%
Excess remuneration and windfall profits for PV industry	0%	0%	11%	7%
Risk of losing public acceptance for policy and technology	0%	0%	2%	2%
Risk ofhurting domestic PV industry	0%	0%	16%	4%
Increased power intermittency and power regulation	3%	7%	5%	17%
Risk ofreduced grid stability	0%	7%	9%	22%
Lack ofmarket integration	0%	0%	3%	21%

Prevalence > 10%
Prevalence > 20%

the average customer purchasing price was much too low to cover costs of PV power producers.

Throughout its reign, the CDU/FDP government opposed any increase in the FIT for PV with the argument that subsidizing the technology was uneconomic and further market interventions should be avoided (D3 and D5). Instead it was stressed that due to the early stage of development, support for R&D and demonstration was best suited to advance PV (D10). Politicians of the Social Democratic Party (SPD) and Greens, on the contrary, emphasized the importance of a mass market for lowering the costs of PV (D8). They pointed to the fact that other countries, such as Japan and the US, had already established more comprehensive market support schemes, raising concerns that Germany might lose the international race for PV industry development (D4, D6, D9, and D10). Moreover, especially the Green party considered the broader market support of PV a means to break the market power of the large German utilities (D8).

When in 1998 the CDU/FDP government was replaced by a coalition consisting of the SPD and the Green Party, the new government set up a completely new feed-in law, the Renewable Energy Sources Act ('Erneuerbare Energien Gesetz' (EEG) – D11).[8] The law consisted of 12 articles and was adopted on the 1st of April 2000. Similar to the first Feed-in Law, the EEG granted independent producers of PV access to the electricity grid if a grid connection was "necessary and economically feasible". Beyond this, however, for the first time the law included a PV-specific remuneration of 51 EUR cents/kWh[9] at which grid operators had to purchase the generated electricity over a guaranteed period of 20 years. The remuneration paid by the grid operator was forwarded to the electricity utility which apportioned the extra costs (so-called 'EEG apportionment') to the electricity price of the end consumer. Only utilities whose total sales included more than 50% of FIT-eligible electricity were excluded from having to collect the EEG apportionment, creating an extra incentive for utilities to increase their share of renewables in their electricity portfolio. To account for the expected decreases in the cost of PV resulting from technological

[21] Difference costs are calculated as the difference between the total annual expenses for supporting renewables (FIT remuneration, balance energy) and the revenue from selling renewable electricity at the wholesale market. Dividing the difference cost by the volume of electricity produced under the FIT scheme yields the EEG apportionment.

[22] According to the law, the target corridor for the dynamic degression should change over time. E.g., in 2011 the FIT should be adjusted up- or downward if in the previous 12 months the annual installed capacity was <1200 MW or >1900 MW.

[23] The option of self-consumption, despite being in the law, was not applicable at first due to the lack of an implementing decree.

[8] The Minister of Economic Affairs, Werner Müller, opposed the idea of a FIT scheme and favored green electricity standards as a voluntary option or a quota system. The parliamentary groups of the Greens and the SPD outmaneuvered him by devising and passing their own law.

[9] All monetary values in this document are expressed in nominal terms.

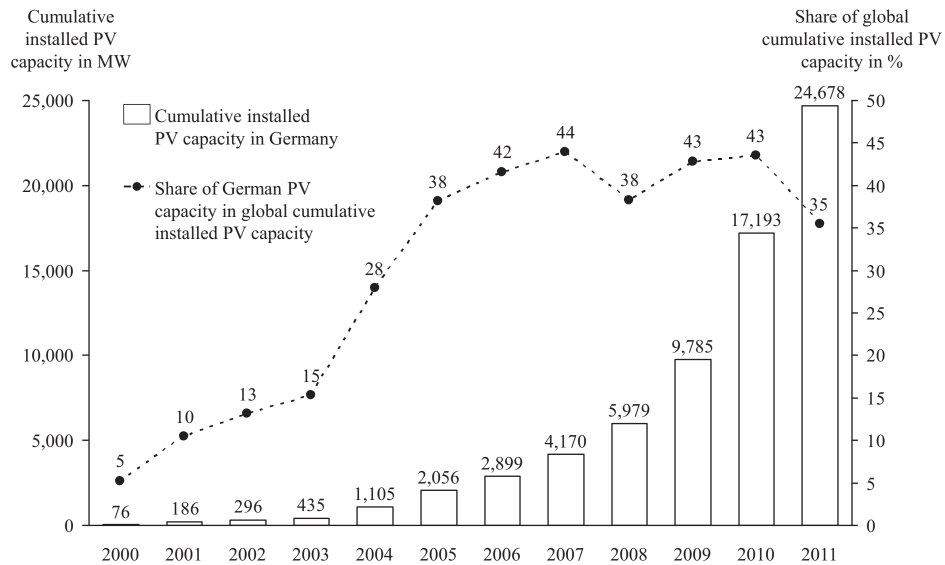

Fig. 1. Cumulative installed PV capacity in Germany.
Data from BMU (2012) and EPIA (2012).

learning and economies of scale, the law included an annual degression of 5% in the FIT for newly installed plants as of 2002.[10]

In combination with low-interest loans provided under the 100,000 roofs program, the significant increase in the remuneration for PV led to a surge in the market for PV technologies. Annual installed capacity escalated from only 9 MW in 1999 to more than its 15-fold in 2003 (see Fig. 1). The first experience report on the EEG, commissioned by the German Bundestag and published in June 2002, noted that PV showed the smallest contribution to the electricity generation (0.05% in 2001) but the highest growth rates (D12). The EEG was subtly rated a success and it was expected that the additional incentives set by the 100,000 roofs program could be abandoned in 2004.

5.2. *Phase 2: removing barriers to market growth (2000–2004)*

With the EEG providing a sufficient financial incentive for an increased investment in PV, two issues emerged that the 2000 version of the EEG did not take into account. First, to allay concerns among opposition parties and consumer associations that the EEG would lead to steep increases in electricity prices, the EEG 2000 included a cap of 350 MW for the maximum cumulative installed capacity to be covered by the feed-in tariff. Simultaneously, the plants eligible for the remuneration were limited to a maximum size of 5 MW for roof-mounted PV and 100 kW_p for other facilities. In the view of an emerging domestic PV industry, both of these factors were considered potentially harmful barriers to the opportunity of establishing a leading market position and exporting domestic PV technology (D12). Second, with increasing deployment the share of the EEG apportionment in the end consumer electricity price rose from 0.2 EUR cents/kWh in 2000 to 0.4 EUR cents/kWh in 2004 which led to concerns about potential competitive disadvantages for energy-intensive sectors (D14 and D16).

To address these issues, in 2002 the German Bundestag adopted an addition to the EEG which raised the ceiling to 1000 MW (D13). Moreover, in a first amendment of the EEG in July 2003, an article was added that limited EEG apportionment for large electricity consumers that (a) faced international competition and (b) had an electricity consumption of more than 100 GWh and a share of electricity costs in gross value added of more than 20% to 0.05 EUR cents/kWh (D15).[11] In a second amendment in December 2003 (D18), the ceiling and the limit to eligible plant sizes were completely removed. For roof-mounted PV the remuneration was raised to up to 57.4 EUR cents/kWh which was justified by the fact that with the end of the 100,000 roofs program private households could no longer apply for complementary low-interest loans (D19). All of these changes were mainly promoted by the SPD/Green government coalition. Yet, the EEG also enjoyed support by many politicians in the CDU who, while pointing to areas of improvement, praised its general effectiveness (D14 and D17).

In July 2004 the EEG 2000 with its additions and amendments was substituted by a completely overhauled new EEG, consisting of 21 articles (D20). The revision had officially been stipulated in the EEG of 2000 and reinforced the development reflected in the previous additions. Several articles were added that detailed the processes of remuneration payment and grid connection to ensure a higher investment security of independent power producers. Furthermore, the limitation of the EEG apportionment for large electricity consumers was extended to include all companies that used more than 10 GWh of electricity and had a share of electricity costs in gross value added of more than 15%. Similar to the 2003 amendments, the EEG 2004 was championed by the SPD/Green government. The CDU would have supported the legislation if it had been set to run out by 2007.

The increase in the remuneration for rooftop PV and the removal of the ceilings for maximum plant size led to a fundamental boom of installations in Germany. The installed capacity rose from 435 MW at the end of 2003 to almost 6 GW at the end of 2008. The 2007 experience report noted that the 2010 target for deployment of PV would already be reached at the end of 2007 (D27). Due to its positive effects on domestic job creation, CO_2-free electricity supply and innovation, the overall assessment of

[10] It is important to note that the degression mechanism leaves the tariffs of installed plants unchanged, i.e., plant operators are guaranteed the FIT tariff at the time of installation throughout the twenty years, irrespective of later changes in legislation.

[11] The exceptions for large electricity consumers were also supported by the opposition party CDU.

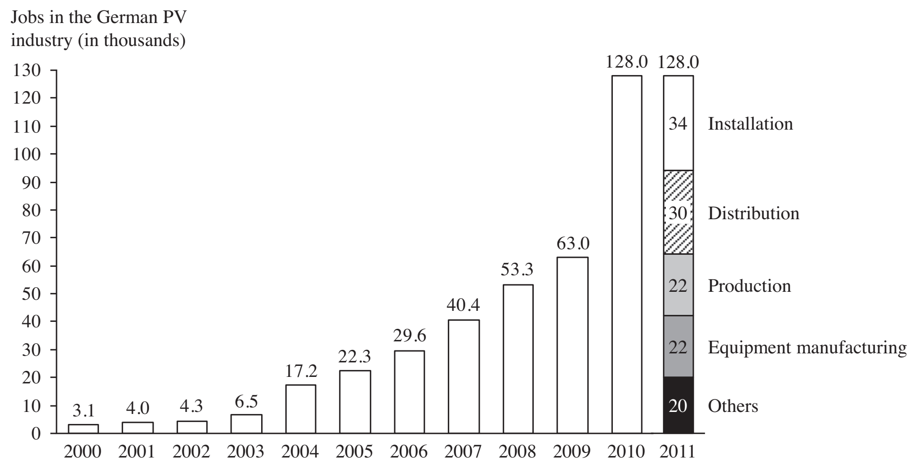

Fig. 2. Development of jobs in the German PV industry.
Data from BSW Solar (2012).

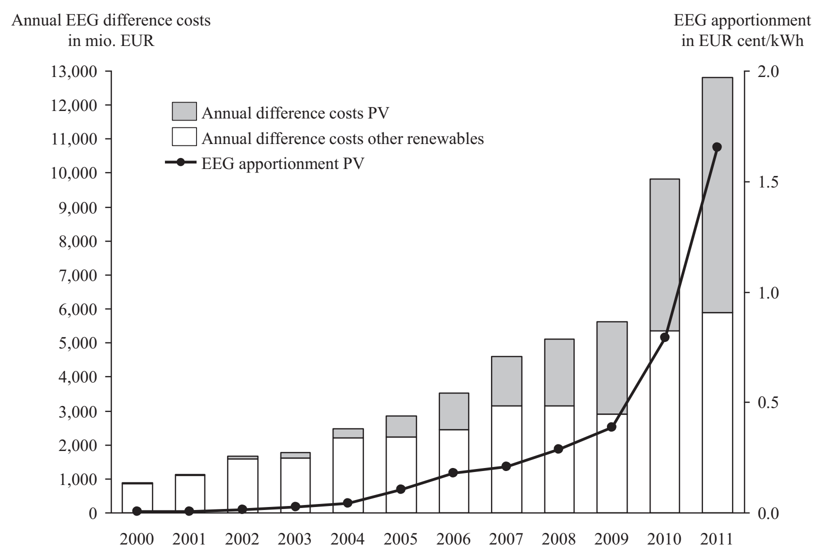

Fig. 3. Development of annual EEG difference cost and apportionment for solar PV in Germany.
Data from BDEW (2011).

the law was very positive. Especially the growing number of jobs in firms producing and installing PV modules and manufacturing equipment (see Fig. 2) led to an unprecedented excitement among politicians of all parties. In many debates, the EEG was praised as a success story (D22, D23, D26, D28, D29 and D30). Even the FDP, which as the only party favored “market-based instruments”, such as tradable green certificates over a FIT, urged measures to support the export of German PV technology (D24 and D25).

5.3. *Phase 3: limiting rising costs for society (2004–2011)*

Prior to 2006 the SPD and the Green Party, as the originators of the EEG, had been able to justify the public costs for PV by pointing to the positive economic, ecological and social side effects of the FIT which were supposed to outweigh the investments in the medium term. Furthermore, politicians of both parties pointed to the large amounts of public spending that had been directed to other energy technologies, e.g., nuclear power, in the past (D17). In contrast to this, some members of parliament of the CDU and FDP voiced criticism regarding the high social costs resulting from the FIT for PV, e.g., in a large interpellation in 2004 (D21). However, all parties generally shared the goal of supporting PV and especially after a government consisting of SPD and CDU had been elected in 2005, critics of the EEG in the CDU maintained a low profile.

With the steep increase in deployment that occurred from 2004 to 2008, the costs that had to be borne by the electricity consumer became increasingly significant and the focal point of the political debate. In 2008, the extra cost for electricity consumers due to PV support through the FIT amounted to almost 2 bn EUR – an increase of more than 600% compared to the level of 2004 (see Fig. 3). In addition, it showed that production costs for PV modules during the years 2004–2008 had decreased at a much faster rate than the remuneration paid through the FIT system (D34). These cost reductions, which were the result of successful innovation efforts of firms and economies of scale, led to considerable windfall profits for technology and power producers (D31 and D34).

In response to these challenges, in 2009 a new EEG was enforced which contained specific measures to “dampen the market

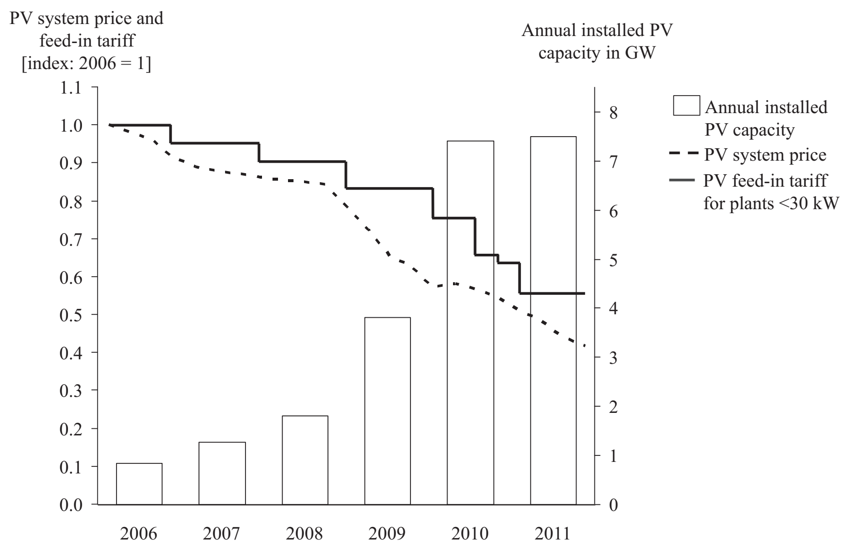

Fig. 4. Development of feed-in tariff, PV system price and annual installed capacity of PV in Germany. Data from BMU (2011), BSW Solar (2012) and EPIA (2012).

development", limit additional costs for consumers and reduce windfall profits (D33). As the most significant change, the static degression of 5% was substituted by a dynamic degression ('flexible ceiling') which meant that the level of remuneration paid for new plants was dependent on the installed capacity of PV in the previous year. This new mechanism, which had been suggested by the Green Party to avoid a fixed ceiling, was supported by all parties except the LINKE (D32). As a measure to reduce adverse effects of PV on grid stability and avoid investments in distribution grids, the 2009 amendment of the EEG also introduced targeted incentives for self-consumption of electricity. Furthermore, based on recommendations in the 2007 experience report, the amendment to the EEG in 2009 contained a new article which required plants with a size larger than 100 kW to implement a remote control and power measurement unit. This measure was meant to provide grid operators with the possibility to disconnect larger plants from the grid in case of instability. To make up for the financial losses occurring during such a period of transitional grid enforcement, plant operators were legally guaranteed compensation at the level of lost income. The EEG 2009 also reformed the redistribution mechanism underlying the EEG apportionment. Instead of purchasing the electricity and bundling it into contracts to be sold to electric utilities, grid operators were now required to directly market the electricity bought from PV plant operators at the electricity spot market. Moreover, to slowly integrate the renewables into the market and reduce mismatches between electricity demand and the supply, the EEG 2009 also introduced the option for plant operators to forgo the FIT and directly market their electricity to third parties.

Despite the (moderately) increased degression of FIT levels, deployment of PV kept rising at strong rates. Due to overcapacities among producers of PV modules, an increasing supply of low-cost modules from Asia (especially China) and a significant drop in prices for the raw material silicon (D38, D39, and D40), PV system prices plummeted by 29% from 4225 EUR per kW_p at the end of 2008–3000 EUR per kW_p at the end of 2009 (see Fig. 4). Since the FIT level declined at a much lower pace, profits of both producers and investors rose. Together with the breakdown of the Spanish PV market, which now could no longer absorb the large quantities of PV modules produced (D38), this led to a record capacity of 3.8 GW being installed in Germany in 2009. The fact that this further raised the annual difference costs to be carried by consumers was deemed particularly undesirable since the market share of German manufacturers in global PV cell production had fallen quite significantly since 2007 and more and more modules installed in Germany were supplied by Chinese manufacturers (see Fig. 5). Supporters of the EEG pointed to the fact that, despite the rising market share from Chinese suppliers, Germany maintained a stronger position in the fields of inverters, manufacturing equipment and poly-silicon production (see Fig. 6). Nevertheless, a number of media reports appeared that saw the FIT itself as one of the main reasons for the competitive disadvantage of the German PV industry which, in the face of generous support had neglected technological innovation and geographic diversification (D35 and D43). Formerly quoted as exemplary, the support for PV was now criticized even by advocates of the German FIT system who worried that the developments within PV could reduce the public acceptance of renewables and undermine the legitimacy of the FIT system as a whole (D37, D47, D48, D49, D51, and D52).

In reaction to these developments, the conservative government consisting of CDU and FDP, which had replaced the CDU/SPD government in September 2009, introduced a legislative draft according to which FIT levels of PV ought to be cut by 20% (D36).[12] Although, particularly in the later phases of the legislative process, there was a general consensus among all parties that the level of the FIT for PV had to be reduced, SPD, Greens and LINKE opposed such drastic reductions, pointing out that they would hurt the domestic industry and that windfall profits in the PV industry were negligible compared to the profits made by the large utilities (D35, D41, and D42). Finally, in August 2010, an amendment of the EEG was enforced that significantly reduced remuneration for all system sizes retroactively for July 2010 (D46). Degression for 2010 and 2011 was adjusted upward. Furthermore, two one-time reductions were applied which lowered remunerations by 10% and 3% in July and October 2010 respectively. The fact that reductions were much lower than originally envisioned was mainly

[12] The fact that, despite previous opposition by the FDP, the FIT was not abandoned by the conservative-liberal government can be attributed to the fact that solar power enjoyed widespread support in the German population and that with 60,000 jobs the industry had become an important economic factor. Interestingly, even within the FDP the EEG was supported by the majority of the members. For example, in May 2009 a motion that endorsed the EEG and was binding for the FDP leadership was accepted by the floor of the party convention.

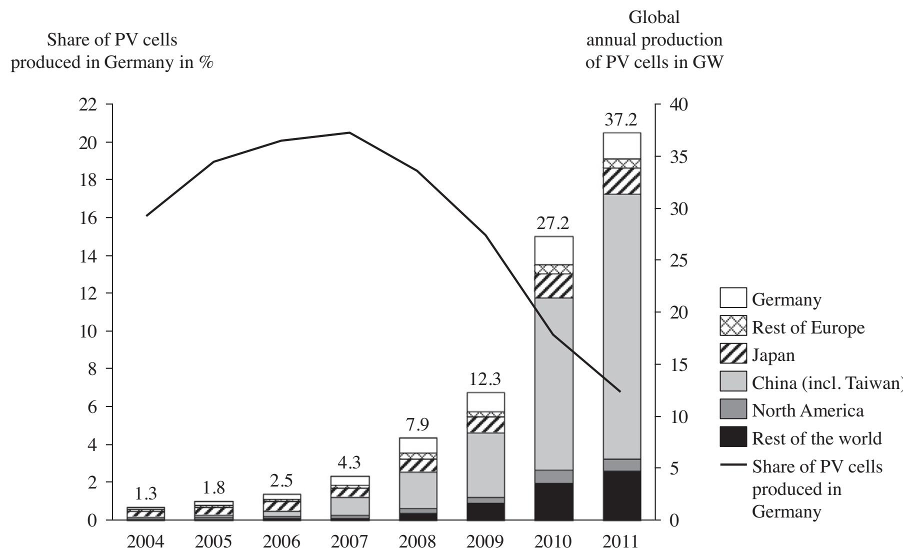

Fig. 5. Global PV cell production and share of PV cells produced in Germany. Data from Photon (2012).

due to the fact that conservative representatives from eastern states, in which the majority of PV cell and module producers are located, opposed any one-time reductions in the FIT beyond 10% (D44).

Despite these measures, annual installed capacity in 2010 reached an all-time high of more than 7.4 GW. Therefore, degression rates were further raised in another amendment of the EEG in May 2011 (D53), such that the FIT levels at the beginning of 2012 reached a level of only 40% of those in 2004. Opposition to these cuts in the FIT was limited (D50 and D51). In 2011 another record capacity of 7.5 GW was installed that considerably exceeded the target corridor of 2.5–3.5 GW annually. With annual difference costs amounting to more than 6.8 bn EUR in 2011, costs remained an important topic in the public and political debate preceding the adoption of the EEG 2012.[13]

5.4. Phase 4: ensuring the seamless integration into the market and the electricity grid (since 2011)

With the EEG 2012 the CDU/FDP government further extended the reductions in the EEG apportionment for energy-intensive companies, officially to alleviate potential negative consequences from rising electricity prices.[14] Since this implied an additional rise in the EEG apportionment for non-privileged consumers, Greens, SPD and LINKE accused the government of not being interested in lowering the burden for consumers (D56 and D57). At the same time, however, with PV deployment strongly rising and prices of PV systems strongly declining, two important questions other than social costs moved higher up on the political agenda: (1) how to integrate the increasing capacity of intermittent power into the electricity grid without compromising its stability and (2) how to structure incentives in a way that allows seamlessly phasing out the FIT scheme once cost competitiveness is reached (D54).

After deployment continued to rise in 2009 and 2010, the issue of grid integration gained increasing prominence. While some experts did not see any immediate problems with regard to the grid (e.g., Christian von Hirschhausen, German Institute for Economic Affairs), others openly warned of “considerable conflicts” (Rainer Baake, German Environmental Aid, D45) and “massive problems” (Stephan Kohler, German Energy Agency, D54) with grid stability if no measures were taken. Hence, the question of grid integration was taken on more seriously in the political debate and addressed in the EEG 2012 (D57). The new legislation consisting of 88 articles became effective in 2012. Among others, it required new plants of any size to have a remote control, allowing the grid operator to disconnect it from the grid.[15] Furthermore, the fixed remuneration for self-consumption was replaced by a self-consumption bonus paid in addition to substituted retail electricity prices. This measure was expected to foster household investments in energy storage and demand-side management (D54).

To incentivize market integration of PV, the EEG 2012 granted operators a market premium if they renounced the FIT and directly marketed their electricity on the spot market. While in general this step was considered useful by experts, they criticized the decision of the government to simultaneously limit the possibility for utilities to benefit from the ‘Gruenstromprivileg’ (see phase 1), which had previously been the most important scheme for incentivizing direct marketing (D54). Moreover, the direct marketing of PV is complicated by the fact that the change in the redistribution mechanism in the EEG 2009 PV itself had strongly contributed to lowering peak-load electricity prices through the ‘merit order effect’ (D54 and D55). Since in 2012 the costs of PV are still comparatively high, only a very small percentage of PV electricity is directly

[13] That the German FIT for PV remains politically debated is also due to the fact that the ongoing growth of distributed generation poses a threat to the business models of the four large German electric utilities (see, e.g., Becker, 2011).

[14] It is important to note that by the time that the reductions were further extended, a large proportion of the energy-intensive industries were already largely exempted from having to pay the EEG apportionment and simultaneously benefited from lower wholesale electricity prices due to the merit order effect (see above). With the EEG 2012, the possibility of not having to pay the EEG apportionment was extended to smaller companies. Applications for exemptions were handled rather generously by the responsible Ministry of Economic Affairs, to a degree that induced the EU commission to start an investigation on illicit state aid (Nestle and Reuster, 2012).

[15] Only for plants with a size smaller than 30 kW, could the operator alternatively choose to limit the power of the inverter to 70% of the plant capacity, thereby reducing the intermittency of PV electricity.

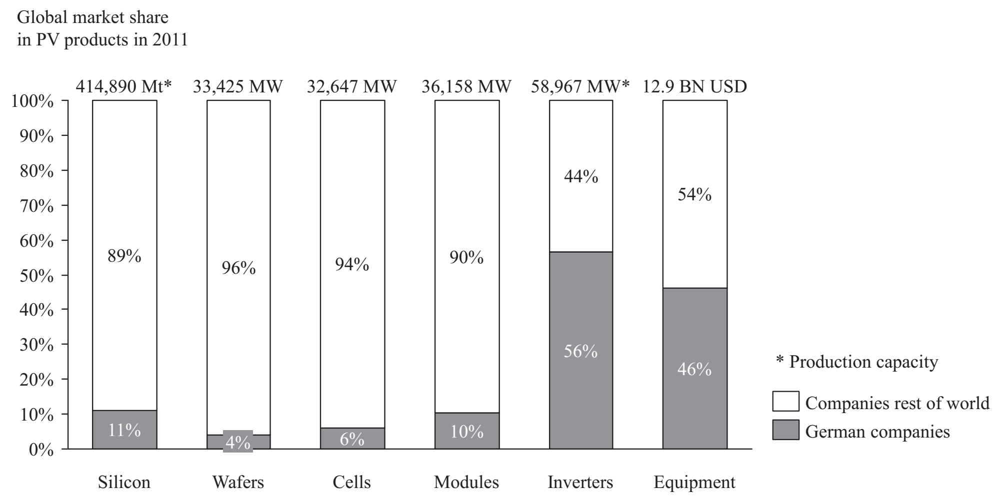

Fig. 6. Global market share of German firms in PV products in 2011. Data from GTM Research, VDMA and NPD Solarbuzz.

marketed. With LCOE having fallen below retail prices, however, direct marketing of PV is expected to play an increasing role in the future as the political support through the FIT can slowly be phased out (D54).

6. Discussion

Based on our analysis of the evolution of the German FIT system for PV, in the following we discuss how policy interventions both drove and were driven by technological change. Building upon this, we propose a theoretical model describing how the complex dynamics of socio-technical systems shape the process of policy interventions targeted at inducing technological change. Finally, we discuss how our study might contribute to an improved integration of the literature on innovation systems and policy learning.

6.1. The German FIT as an example of policy learning

The description of our findings in Section 5 shows that the German feed-in tariff system for PV went through a large number of legislative changes, each of which addressed specific issues in the socio-technical system. In part, these changes can be explained through characteristics of and factors residing in the political system. For example, the legislative changes in the exemptions implemented for energy-intensive industry have been strongly driven by party politics. Similarly, the decision to first implement, later raise and finally remove the ceiling to the maximum cumulative capacity of PV constitutes a typical case of learning among policy makers who initially were not sure about the cost effects that providing a feed-in remuneration for PV would have. In the case of the German feed-in tariff system for PV such changes were facilitated by the fact that, from the start, policy makers were aware that the law had to be revised. Consequently, they implemented a revision cycle that was supported by expert consultations, frequent political interpellations and numerous experience reports commissioned from external authorities. This institutionalization of learning on the side of the policy maker allowed a continuous evolution and adaptation of the legislation.

6.2. Policy-induced technological change as a driver of policy dynamics

While the German FIT for solar PV can therefore be regarded as a good example for how the formal institutionalization of learning mechanisms can support the policy process, our analysis revealed that factors residing in the political system are necessary but not sufficient to explain the evolution of the policy. Rather, we found that many of the changes in the German FIT for solar PV can be traced back to *technological change in the socio-technical system* that policy makers intervened in. While policy interventions often contributed to resolving the issues in focus, in many cases technological change *induced by the FIT scheme* led to the emergence of new, unexpected issues that policy makers addressed in subsequent steps. In the following we present three examples to illustrate this point.

A first example for how technological change influenced policy dynamics are the regulatory changes that policy makers implemented in response to the unexpectedly high rate of policy-induced PV deployment. Since about 2004 the speed of deployment strongly exceeded what policymakers had envisioned or even thought was technically feasible. This rapid diffusion was made possible, amongst others, by innovations in mounting and installation technology, by the emergence of a sophisticated supply chain that allowed new systems to be designed and installed within a matter of days, by innovations in business models and financing schemes, by innovations in remote control systems, inverters and other means of grid integration and not least by spreading knowledge and awareness. The underestimation of the speed of PV deployment led policy makers to significantly misjudge the social cost of the FIT scheme. The German Ministry of the Environment, for example, stated that "in case of the desired, strong growth of renewable energies the burden [for consumers] will amount to mere 0.1 EUR cents per kWh in a couple of years" (BMU, 2000). This quickly turned out to be grossly over-optimistic. By 2003, the EEG apportionment, then still mainly driven by the other renewables, increased to 1.5 cents per kWh. With the surge of PV it escalated to 3.53 cents per kWh, more than the 35-fold of the original estimate, in 2011. As a consequence of this rise in costs, policy makers implemented a number of changes to the FIT. As the overall expenditures for the FIT scheme depend on the amount of annual PV deployment, they conducted a series of reforms of the remuneration rates and the degression mechanism, aimed at slowing down annual installed capacity. Also, the more recent efforts to address issues of grid and market integration can be considered a direct result of high deployment rates. Already in the 1980s, well before FITs were put in place, it was known that deploying large amounts of PV as an intermittent energy source would put stress on the electricity grid (D1). Yet, the fact that the first versions of the EEG up to 2009 did not contain any measures addressing this issue indicate that policy makers did not expect integration of PV capacity to become a problem in the near future. With installed capacity of PV continuously growing at an unpredicted pace, first measures were finally implemented in the EEG 2009 that were directly targeted at enhancing grid stability, such as remote control or the limitation of inverter power. Moreover, in 2012 a highly controversial program was put in place that required operators of PV plants to retrofit existing systems to avoid fluctuations in the power frequency (the so-called '50.2 Hertz problem'), clearly showing that the issue of grid integration had previously been undervalued by regulators.

A second example for how unexpected technological change affected the policy dynamics is the strong reduction in the PV system costs, enabled by the fast PV deployment. From the beginning the German FIT for PV was designed to foster technological innovation and lower the cost of the technology, e.g., by enabling mass production. In view of this, the first EEG already included an annual degression of 5%, which as a policy maker we interviewed reported, had been chosen based on "usual learning rates of comparable industries".[16] However, "technology costs fell much faster than [had] been expected" which was due to "economies of scale and research activities by private corporations which have been sparked by the EEG" (Katharina Reiche, Parliamentary Secretary of the Ministry of the Environment, D34). The complex relationship between demand, production capacity investments, technological change and competition, led to a very erratic cost curve over the last ten years, which required numerous changes to the policy to limit windfall profits for industry. The rapid cost decreases, in turn, contributed to an ever faster deployment of PV, thereby exacerbating existing problems.

Finally, a good example for how the diffusion of technological knowledge – another dimension of technological change – can affect policy dynamics is the rise of the Chinese PV industry. Until 2007, German manufacturers were considered "world market leaders" (D24) and politicians of all parties were enthusiastic about the creation of jobs in an emerging industry which had been an important in developing the FIT. However after 2004, shortages in the supply of wafers, cells, and modules due to the unexpected demand opened up a window of opportunity for Chinese cell and module producers, which were able to generate revenues by selling their products on the German market. The Chinese companies "invested these resources in research and development" (D41) and modern production equipment, which was often supplied by Western equipment manufacturers. By providing the demand and by enabling the corresponding knowledge spillovers, as a policy maker we interviewed admitted, the German EEG itself "played a decisive role in the emergence of the Chinese PV industry".[17] With increasing shares of imported technology, at some point the EEG benefited foreign producers more than the domestic industry. This jeopardized the legitimacy of the entire support scheme and became an important topic in the political discussion on FIT reforms.

Summarizing the previous statements, Fig. 7 provides an overview of the role that policy-induced technological change played in the evolution of the German FIT for PV. It is important to note that this figure does not paint a holistic picture of all drivers of policy and technology evolution in the case of the German FIT for PV but focuses on depicting the interactions between changes in policy and technology.[18] Despite its simplifying nature, the figure indicates that in many ways technological change induced by policy makers led to the emergence of new prevalent issues which, in turn, were addressed by policy makers in subsequent steps. While policy makers tried to anticipate technological developments when crafting legislations, we find that many developments in the technological sphere triggered by policy interventions came as a surprise or were underestimated with regard to timing or scale. As one of the experts we interviewed reported, it is hard for policy makers to proactively address issues since "every change in a detail [of the regulation] can develop a dynamic which you did not intend". In line with this, one policy maker we interviewed expressed that "with the EEG we are getting to the limits of what policy can shape. It is difficult to foresee the development, which is why we constantly have to reconfigure the legislation". When developing schemes for market support, policy makers therefore "have to react to the tempestuous technological developments in the market. Over and over, we will have to react." (Dr. Norbert Röttgen, former German Minister for the Environment, D43). While in many other countries the challenge of reacting to unexpected issues might have induced policy makers to cancel (or not even start) the support scheme, in Germany the high public support for renewables and PV, the existence of a domestic industry with related jobs and the political will of keeping markets open to new entrants prevented such a development.

6.3. Framework 'compulsive policy-making'

In order to translate our findings into a more abstract representation we propose the theoretical framework depicted in Fig. 8, that directly addresses our research question of how the complex dynamics of socio-technical systems shape the process of policy interventions targeted at inducing technological change. We suggest that at each point in time, political discussions revolve around a number of prevalent issues in the socio-technical system (1). When designing policy incentives (2), policy makers directly address these issues and also try to foresee future ones. In general, however, changes in policies are only directed to a small subset of particularly prevalent issues and rarely present accurate answers to less immediate, future issues. This can be explained by the fact that, in general, policy makers possess limited capacity and foresight (a). More importantly, however, policy interventions (c) themselves often lead to technological change (3) that may resolve the immediate bottleneck but, through complex system interdependencies (e), leads to the emergence of new issues (1). These issues in turn, are addressed by policy makers by changing the focus in policy design and adjusting existing policies (2). The time it takes for issues to be resolved varies considerably depending on the detailed nature of the issue. As a result, changes in policy design are usually directed to a number of novel issues while simultaneously addressing older, persisting ones.

[16] Although the degression of 5% turned out as too low for PV, it was much lower for the other technologies under the EEG.

[17] It should be noted that the emergence of the Chinese PV industry was strongly driven by the decision of the Chinese national and provincial government to offer strategic support for the sector, e.g., by offering low-interest loans through the Chinese Development Bank (see e.g., Grau et al., 2012).

[18] For example, in contrast to Fig. 8, the figure does not consider the role of politics or foreign policies for the dynamics of policy and technologies.

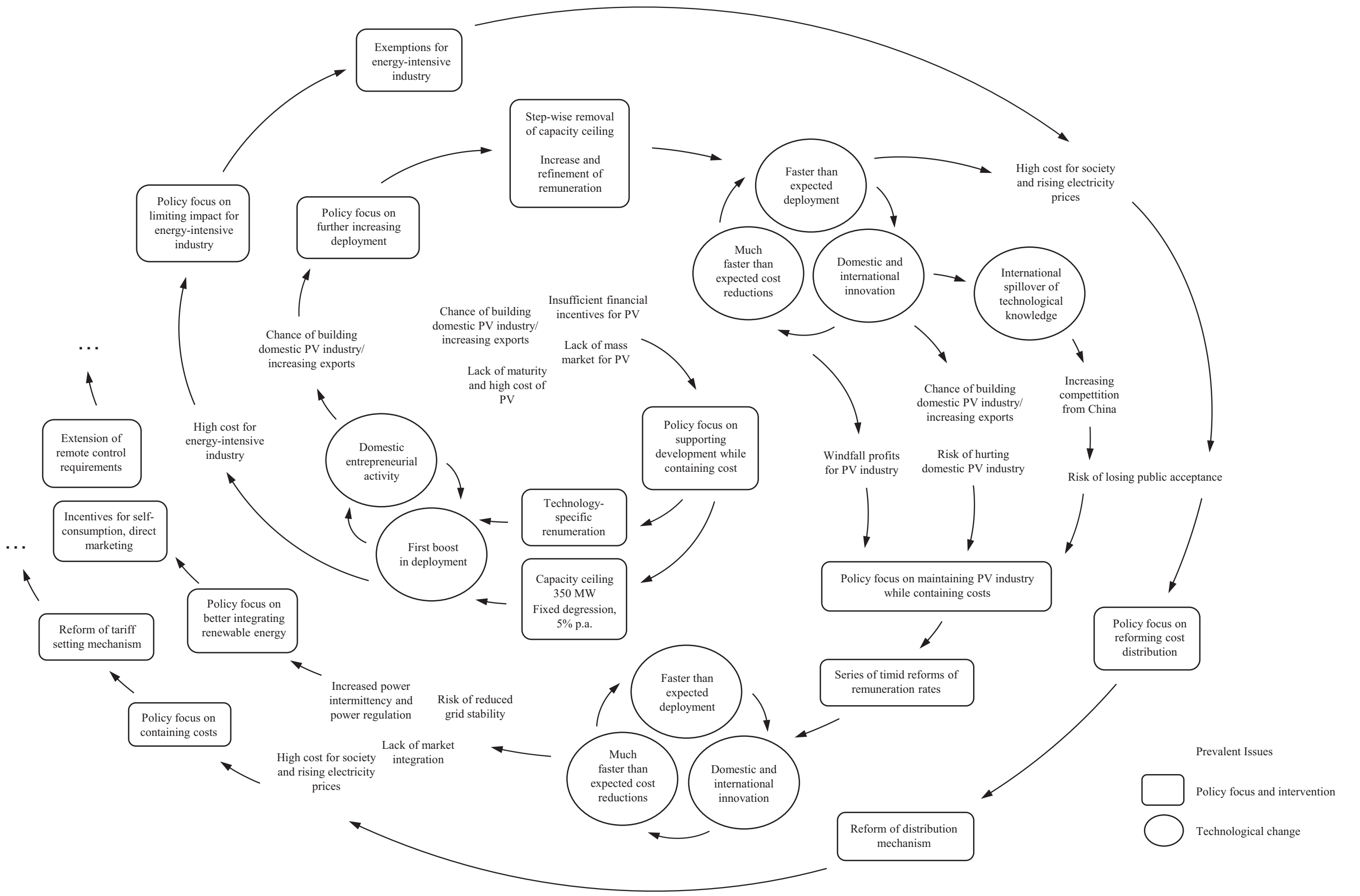

Fig. 7. Simplified representation of how policy-induced technological change drove policy dynamics in the evolution of the German FIT for solar PV.

While the majority of issues we found in the history of the German FIT for PV can be considered at least partly self-inflicted, there were also developments within the socio-technical system that were beyond the direct control of German policy makers, e.g., the collapse of the Spanish market in 2009 that raised installations in Germany (d). Furthermore, throughout the evolution of the German FIT system for PV changes in policy design were impacted by politics (b). In the early phases of the German FIT system for PV, developments were strongly driven by political interests and opportunities, such as reducing the market power of large utilities and supporting a domestic PV industry. In the further evolution of the German FIT system for PV, however, unforeseen issues emerged that exerted direct pressure on policy makers to change the policy design. Political debates became more technical with policy makers increasingly *reacting to* rather than *proactively shaping technological change*. Despite remaining considerable discrepancies between the political parties regarding the appropriate means, a broader consensus can be observed that particular issues (e.g., rising social costs or looming grid instabilities) needed to be tackled.

We argue that the cycle of issues and solutions we describe in Fig. 8 shows strong similarities with what Rosenberg (1969) labeled 'compulsive sequences'. Studying the evolution of technical systems in the machine tool industry, Rosenberg finds that at any given time firms in the industry focused their search processes on a small number of clearly identifiable problems which constituted the bottleneck of the technical system. Eventually, this search then led to a change in the system which resolved the bottleneck. However due to interdependencies between the system elements, the resolution of the bottleneck caused new bottlenecks in the system to emerge. Since these needed to be resolved to further increase the performance of the technical system, the firm's direction of technical search shifted to the new bottleneck, leading to a continuous cycle of problems and solutions that shapes the evolution of technical systems.[19]

While obviously there are a number of important differences between a firm trying to improve a technology and policy makers intervening in a socio-technical system (e.g., in terms of the number of actors involved and the decision making process), we maintain that the general pattern is surprisingly similar. Building upon Rosenberg's terminology, we therefore label the process shown in Fig. 8 'compulsive policy-making'.[20] It is important to note that in this context, 'compulsive' does not imply a lack of agency of policy makers in the political process. Rather, it describes the general phenomenon that interventions in socio-technical systems targeted at inducing technological change alter the configuration of the system, thereby causing changes in the prevalent issues and exerting a pressure on policy makers to change the focus in policy design.

The difference between the presented framework and existing frameworks of policy learning – such as Lindblom's (1959)

[19] Rosenberg's concept of 'compulsive sequences' was later taken on by Hughes' (1983) in his work on large technical systems. Similar to Rosenberg, Hughes suggests that complex systems evolve in an uneven manner since at each point in time there are particular system components – so-called 'reverse salients' – that lag behind other system components (e.g., in terms of efficiency). Since these reverse salients are interconnected with the other system components, their presence retards the overall performance of the technical system. Therefore, Hughes suggests that at each point in time innovative activity will concentrate on 'correcting' the reverse salient.

[20] In fact, in a footnote of his original article Rosenberg (1969, p. 23) himself points to parallels between his framework and the political process.

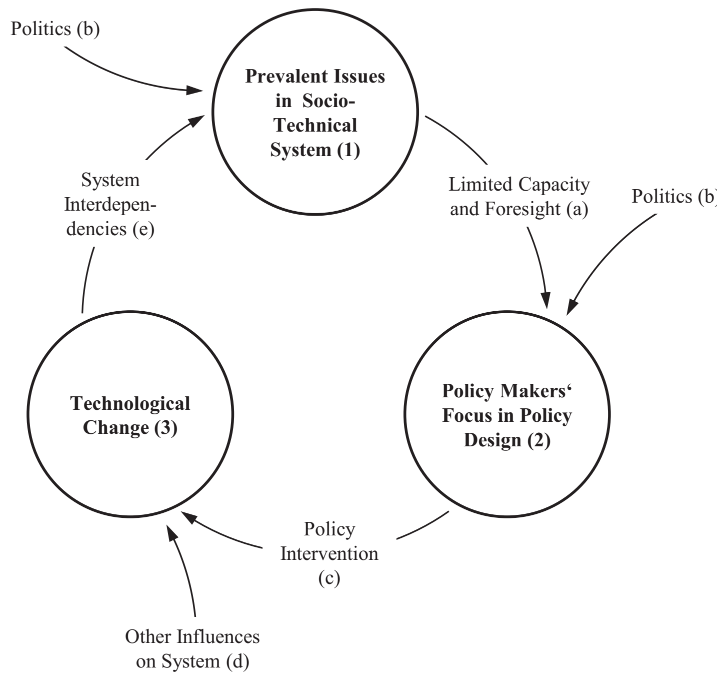

Fig. 8. Framework 'compulsive policy-making'.

'science of muddling through' – is that 'compulsive policy-making' focuses on the influence of technological change on the dynamics of policy-making. The literature on policy learning primarily explains the iterative nature of the policy process based on *factors residing in the political system*. For example, Lindblom stresses the limited capacity of public administrators in dealing with complex problems as the main cause for policy iterations. Policy makers cannot go through the process of identifying all possible goals and values, listing all possible policy measures and choosing the best one. Therefore, according to the framework of 'muddling through', they pick a solution that best suits their immediate needs and are forced to make subsequent changes to the policy to correct for earlier mistakes. The concept of 'compulsive policy-making' also tries to explain the iterative nature of the policy processes. However, complementing existing concepts in the literature on policy learning, it focuses on *factors residing in the socio-technical system that policy makers attempt to change* as an explanation for policy dynamics. We argue that even if policy makers have the capacity and knowledge to design a policy that resolves a prevalent issue in the short-term, endogenous technological change induced by the policy measures can lead to a situation where unforeseen issues emerge that need to be addressed by policy makers in the future. In this sense, our framework points to an important driver of policy change other than policy failures, changes in political majorities or exogenous changes in the wider socio-economic environment (e.g., demographics or the world economy). Moreover, by drawing on the concepts of system issues and interdependencies, our framework describes concrete mechanisms rooted in the socio-technical system that affect the direction of policy-making.

In general, we would expect compulsive policy-making to be present in most policy fields as most policies will induce some technological change if the latter term is just defined broadly enough. Hence, policy-induced technological change operates in parallel with other dynamics driving policy learning. Still, we propose three criteria that define the conditions under which compulsive policy-making is likely to play a particularly important role: (1) the policy under consideration has a strong innovation policy component, such that it triggers technological change (see arrow 'c' in the framework), (2) policy plays an important role in driving technological change in the socio-technical system compared to other influences (arrow 'd'), such that technological change is largely endogenous and (3) the elements in the socio-technical system are interdependent, such that the outcome of policy interventions has systemic implications and is hard to foresee (arrow 'e'). For example, implementing a change in income tax is not likely to induce strong dynamics of compulsive policy-making, simply because the direct effects of this policy change on technological change are probably limited. On the contrary, we would expect compulsive policy-making to be more prevalent in the case of stem cell research as all previously mentioned criteria are fulfilled to a larger extent.

Overall, a main benefit of our framework lies in providing an additional lens on the drivers of and need for policy change, particularly in the context of innovation policies, as it draws attention to mechanisms that have not previously been stressed in the literature on policy learning. We suggest that a critical task in designing effective policies targeted at fostering technological change lies not only in developing adequate governance mechanisms based on existing knowledge but in *investing resources into better understanding the dynamics of the system to be intervened in.* Our study stresses the potential that lies in developing a profound knowledge about processes related to technological change and leveraging this knowledge when designing corresponding policies. For example, while according to learning curve theory, cost reduction in solar PV technology is a function of deployment, German policy makers chose a degression mechanism that reduced the remuneration for newly installed plants as a function of time. A more profound understanding of the dynamics underlying cost reductions at the time of policy development might have prevented many of the iterations we have seen. Due to the complex nature of socio-technical systems it does not seem generally possible to accurately foresee the outcome of policy interventions based solely on the analysis of historical cases. Therefore, we suggest making system analysis an integral part of policy monitoring. Rather than only tracking the outcome of policy interventions, policy makers should try to understand the root cause of unexpected technology dynamics and their relation to policy. In this context, it seems important to develop close ties to industry and research institutions to develop a profound knowledge of the drivers of technology developments, which can then be leveraged to continuously improve regulations.

A profound understanding of system dynamics is also *important for policy makers who wish to adopt policy instruments that are already successfully used in other countries*. Our study shows that the effectiveness and appropriateness of policy instruments at any given time is at least partly conditional on previous policy interventions and resulting changes in the socio-technical system. This implies that, although policy makers should leverage the lessons learned in other countries, there is a limit to which policy features implemented in other countries can be successfully copied. For example, the diffusion of solar PV in the German socio-technical system may now have built up enough momentum, e.g., in the form of trust in the system and vested interests, that the system can wither policy interventions aimed at increasing the cost effectiveness or grid friendliness of the policy support. Introducing measures such as the mandatory direct marketing of renewable power in a nascent system without the same history of PV deployment may not show the same positive effects as in the German context as they may induce investment uncertainty and derail the diffusion of the technology before it has even picked up momentum.

6.4. Innovation systems and policy learning: toward an integrated framework

By stressing the role of policy learning and adaptation in the context of innovation systems, our framework represents a first step toward a closer integration of the literature on innovation systems with the work on policy learning. Up to this point, there has been little academic work connecting these two streams of literature. Our empirical analysis of the German FIT system for PV suggests that this current divide is unfortunate as the approaches hold a lot of potential for informing each other. The innovation systems approach represents a powerful heuristic for identifying system failures (or issues) but tends to underestimate the effect of politics and limited foresight. In contrast, the literature on policy learning puts strong emphasis on the inherently political, unpredictable and emergent nature of policy-making. As the rather effective German FIT for solar PV shows, however, this potentially undervalues policy makers' capacity to purposefully alter socio-technical systems. To reconcile these two perspectives, it seems that we require a better understanding of the detailed mechanisms which shape the dynamics of policy interventions in complex socio-technical systems. Our framework builds upon the idea of system failures or issues as the focusing devices of policy change, thereby highlighting the value of systemic, analytical approaches to policy-making, while simultaneously emphasizing technology dynamics and complex system interdependencies as key mechanisms that limit targeted policy interventions.

7. Limitations and future research

Our study has several limitations that lend themselves as avenues for future research. First, one could argue that the case of the German FIT system for PV is special in that with the development of the FIT policy makers in Germany in many ways treaded unchartered trails. The lack of experience with this instrument might have caused problems and iterations, leading to a strong prevalence of 'compulsive policy-making'. However, there is some indication that in fact countries that implemented FIT schemes at a later point in time – notably Spain, the Czech Republic and Italy – went through similar cycles of policy evolution and sometimes drastically altered policy design in response to the emergence of unexpected issues (del Río González, 2008). To better understand the external validity of the framework proposed in this paper, it would be interesting to juxtapose the evolution of FIT systems in different countries and analyze commonalities in their development.

Second, as pointed out in the previous section, it seems likely that the degree to which policy makers can foresee developments and successfully intervene in a socio-technical system depends on the complexity of the system. Given the strongly international nature of the PV industry and the high dynamic at which it has evolved over the last years, compulsive sequences might be more pronounced for the innovation system for PV than for simpler, geographically bounded systems. Moreover, the observations of compulsive sequences may be specific to interventions in early-stage innovation systems which experience unstable industry structures, fast technological learning and high rates of growth. Future research seems necessary to examine the existence of compulsive policy-making in innovation systems for technologies other than PV.

Third, future studies should investigate to which extent the findings of our analysis for FITs can be generalized to other policy instruments and policy mixes. During our analysis we found that the German FIT system has been complemented by a number of policy measures, such as demonstration programs, industry policy measures, export initiatives and grid infrastructure incentives. These additional measures very closely followed the prevalent issues in the socio-technical system and – like the FIT – drove their occurrence, which provides some first evidence that our framework might be applicable to other forms of policy interventions and policy mixes.

8. Conclusion

With this paper, we contribute to a better understanding of the dynamics that ensue when policy makes engage as system builders to induce technological change. The literature on innovation systems suggests identifying and removing so-called system failures to foster the development and diffusion of technologies. Currently, however, it remains unclear how complex system interdependencies limit policy makers' ability to purposefully intervene in socio-technical systems. To investigate this question, we studied the evolution of the highly effective and widely copied German feed-in tariff system for solar photovoltaics as a policy instrument targeted at 'market formation'. We find that at each point in time, policy makers in Germany directed their attention to a limited number of issues that were considered particularly important for an efficient deployment of solar photovoltaic technologies. Policy interventions often successfully resolved existing issues, making the German FIT for PV a good example for policy learning. At the same time, however, by inducing technological change, each policy intervention also altered the socio-technical system in a way that brought new issues to the fore. The newly emerged issues subsequently became the target of subsequent policy efforts, leading to a continuous cycle of policy makers inducing and reacting to technological change. In analogy to what Rosenberg (1969) called 'compulsive sequences' we label these cycles 'compulsive policy-making'. Our framework complements existing theories of policy learning by pointing to the important role of complex dynamics of socio-technical systems – particularly technological change – as a driver of policy change. By describing how system dynamics may simultaneously limit and drive targeted policy interventions, our study represents a first step toward a closer connection of the literature on innovation systems with the work on policy learning.

Acknowledgements

The authors would like to thank Anna Bergek, Stefano Brusoni, Laura Diaz Anadon, Lea Fuenfschilling, Thilo Grau, Volker Hoffmann, Florian Kern, Jochen Markard, Michael Peters, Tobias Schmidt, Tammy-Ann Sharp, Jan-Peter Voß and Jim Watson for their valuable comments and suggestions on earlier drafts of this article. We are particularly thankful to Erik Gloerfeld who contributed to the development of the core idea. Previous versions of the paper were presented at the International Schumpeter Society Conference 2012 in Brisbane, Australia, the International Conference on Sustainability Transitions 2012 in Copenhagen, Denmark, the Third Berlin Forum Innovation in Governance 2012 in Berlin, Germany, and the Harvard Energy Policy Seminar in Cambridge, Massachusetts, in March 2013. We are grateful for the feedback received by the conference, seminar and workshop participants. Moreover, we would like to acknowledge the highly constructive comments we received by two anonymous reviewers that helped refine the arguments presented in the article.

Appendix A.

Table A.1
List of most important documents.

ID	Date	Translated document title	Original title
D1	24/09/1990	Report by the Enquete Commission "Shaping the technological development: Technological impact assessment and evaluation": Conditions and consequences of strategies pertaining to building a solar hydrogen economy	Bericht der Enquete-Kommission "Gestaltung der technischen Entwicklung; Technikfolgen-Abschätzung und -Bewertung": Bedingungen und Folgen von Aufbaustrategien für eine solare Wasserstoffwirtschaft
D2	07/12/1990	Legislation on the feed-in of electricity from renewable energies into the public grid (Feed-in law)	Gesetz über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz (Stromeinspeisungsgesetz)
D3	17/03/1994	Response by the German government to the major interpellation by the Green Party: Success record of the German government with regard to climate protection	Antwort der Bundesregierung auf die Große Anfrage der Gruppe BÜNDNIS 90/DIE GRÜNEN: Klimaschutz-Erfolgsbilanz der Bundesregierung
D4	05/04/1994	Response by the German government to the minor interpellation by the SPD: Future of the solar industry in the Federal Republic of Germany	Antwort der Bundesregierung auf die Kleine Anfrage der Fraktion der SPD: Zukunft der Solarwirtschaft in der Bundesrepublik Deutschland
D5	27/07/1995	Response by the German government to the minor interpellation by the Green Party: Future prospects of the photovoltaic industry in Germany	Antwort der Bundesregierung auf die Kleine Anfrage der Fraktion BÜNDNIS 90/DIE GRÜNEN: Zukunftsperspektiven für die Photovoltaikindustrie In Deutschland
D6	13/10/1995	Legislative draft by the Green Party: Draft of a legislation for the revision of the legislation on the feed-in of electricity from renewable energies into the public grid (Feed-in law)	Gesetzentwurf der Fraktion BÜNDNIS 90/DIE GRÜNEN: Entwurf eines Gesetzes zur Änderung des Gesetzes über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz (Stromeinspeisungsgesetz)
D7	18/10/1995	Briefing by the German government: Experience report by the German Ministry of Economy on the Feed-in Law	Unterrichtung durch die Bundesregierung: Erfahrungsbericht des Bundesministeriums für Wirtschaft zum Stromeinspeisungsgesetz
D8	26/04/1996	Legislative petition by the Green Party: 10-point plan for entering the solar age	Antrag der Fraktion Bündnis 90/DIE GRÜNEN: 10-Punkte-Programm für den Einstieg ins Solarzeitalter
D9	13/06/1996	Protocol of the German Bundestag, 110th session, 13th legislative period	Deutscher Bundestag: Stenografischer Bericht, 110. Sitzung, 13. Wahlperiode
D10	04/12/1996	Response by the German government to the major interpellation by the Green Party: support of the photovoltaic industry by the German government	Antwort der Bundesregierung auf die Große Anfrage der Fraktion BÜNDNIS 90/DIE GRÜNEN: Unterstützung der Photovoltaik durch die Bundesregierung
D11	01/04/2000	Legislation on the preferential feed-in of renewable energies (Renewable Energy Sources Act – EEG) as well as on the revision of the Energy Industry Act and the Mineral Oil Tax Act	Gesetz über den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz – EEG) sowie zur Änderung des Energiewirtschaftsgesetzes und des Mineralölsteuergesetzes
D12	16/07/2002	Briefings by the German government: Report on the state of market introduction and cost development of plants for the generation of electricity from renewable energies (experience report on the EEG)	Unterrichtung durch die Bundesregierung: Bericht über den Stand der Markteinführung und der Kostenentwicklung von Anlagen zur Erzeugung von Strom aus erneuerbaren Energien (Erfahrungsbericht zum EEG)
D13	23/07/2002	Legislation on the revision of the Mineral Oil Tax Act and other laws	Gesetz zur Änderung des Mineralölsteuergesetzes und anderer Gesetze
D14	31/01/2003	Protocol of the German Bundestag, 23rd session, 15th legislative period	Deutscher Bundestag: Stenografischer Bericht 23. Sitzung, 15. Wahlperiode
D15	16/07/2003	First legislation for the amendment of the Renewable Energy Sources Act	Erstes Gesetz zur Änderung des Erneuerbare-Energien-Gesetzes
D16	10/12/2003	Response by the German government to the major interpellation by the CDU/CSU: Forward-looking and efficient design of the amendment of the Renewable Energy Sources Act	Antwort der Bundesregierung auf die Große Anfrage der Fraktion der CDU/CSU: Zukunftsorientierte und effiziente Gestaltung der Novelle des Erneuerbare-Energien-Gesetzes
D17	12/12/2003	Protocol of the German Bundestag, 83rd session, 15th legislative period	Deutscher Bundestag: Stenografischer Bericht 83. Sitzung, 15. Wahlperiode
D18	22/12/2003	Second legislation for the amendment of the Renewable Energy Sources Act	Zweites Gesetz zur Änderung des Erneuerbare-Energien-Gesetzes
D19	12/01/2004	Legislative drafts by the SPD and the Green Party: Draft for a legislation on the revision of the law pertaining to renewable energies in the electricity sector	Gesetzentwurf der Fraktionen SPD und BÜNDNIS 90/DIE GRÜNEN: Entwurf eines Gesetzes zur Neuregelung des Rechts der Erneuerbaren-Energien im Strombereich
D20	21/04/2004	Legislation on the revision of the law pertaining to renewable energies in the electricity sector	Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich
D21	19/10/2004	Major interpellation by the CDU/FDP: Renewable Energies in Germany	Große Anfrage der Fraktion der CDU/CSU: Erneuerbare Energien in Deutschland
D22	16/02/2006	Protocol of the German Bundestag, 19th session, 16th legislative period	Deutscher Bundestag: Stenografischer Bericht19. Sitzung, 16. Wahlperiode

Table A.1 (*Continued*)

ID	Date	Translated document title	Original title
D23	28/09/2006	Protocol of the German Bundestag, 54th session, 16th legislative period	Deutscher Bundestag: Stenografischer Bericht 54. Sitzung, 16. Wahlperiode
D24	09/11/2006	Legislative petition by the FDP: Solar Entrepreneurship in Germany – Accepting the challenges, taking the opportunity	Antrag der Fraktion der FDP: Solares Unternehmertum in Deutschland – Herausforderungen annehmen, Chancen nutzen
D25	03/04/2007	Proposed resolution and report by the committee for the Environment, Nature Conservation and Nuclear Safety: Report of the German Energy Agency GmbH (dena) on the state and need for action with regard to the support of the export of renewable energy technologies 2003/2004	Beschlussempfehlung und Bericht des Ausschusses für Umwelt, Naturschutz und Reaktorsicherheit zu der Unterrichtung durch die Bundesregierung: Bericht der Deutschen Energie-Agentur GmbH (dena) über die Bestandsaufnahme und den Handlungsbedarf bei der Förderung des Exportes Erneuerbarer-Energien-Technologien 2003/2004
D26	26/04/2007	Protocol of the German Bundestag, 94th session, 16th legislative period	Deutscher Bundestag: Stenografischer Bericht 94. Sitzung, 16. Wahlperiode
D27	09/11/2007	Briefing by the German government: Experience report 2007 on the Renewable Energy Sources Act (EEG experience report 2007)	Unterrichtung durch die Bundesregierung: Erfahrungsbericht 2007 zum Erneuerbare-Energien-Gesetz (EEG-Erfahrungsbericht 2007)
D28	14/02/2008	Protocol of the German Bundestag, 142nd session, 16th legislative period	Deutscher Bundestag: Stenografischer Bericht 142. Sitzung, 16. Wahlperiode
D29	18/02/2008	Legislative draft by the German government: Draft of a legislation for the revision of the law pertaining to renewable energies in the electricity sectors and changes of corresponding regulations	Gesetzentwurf der Bundesregierung: Entwurf eines Gesetzes zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich und zur Änderung damit zusammenhängender Vorschriften
D30	21/02/2008	Protocol of the German Bundestag, 142nd session, 16th legislative period	Deutscher Bundestag Stenografischer Bericht 145. Sitzung, 16. Wahlperiode
D31	10/04/2008	Protocol of the German Bundestag, 154th session, 16th legislative period	Deutscher Bundestag: Stenografischer Bericht, 154. Sitzung, 16. Wahlperiode
D32	04/06/2008	Proposed resolution and report of the committee for the Environment, Nature Conservation and Nuclear Safety on the legislative draft by the German government on a legislation for the revision of the law pertaining to renewable energies in the electricity sectors and changes of corresponding regulations	Beschlussempfehlung und Bericht des Ausschusses für Umwelt, Naturschutz und Reaktorsicherheit zu dem Gesetzentwurf der Bundesregierung Entwurf eines Gesetzes zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich und zur Änderung damit zusammenhängender Vorschriften
D33	01/01/2009	Legislation for the revision of the law pertaining to renewable energies in the electricity sectors and changes of corresponding regulations	Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich und zur Änderung damit zusammenhängender Vorschriften
D34	03/11/2009	Protocol of written questions including answers by the government received from 27th October to 13th November 2009	Schriftliche Fragen mit den in der Zeit vom 27. Oktober bis 13. November 2009 eingegangenen Antworten der Bundesregierung
D35	26/02/2010	Protocol of the German Bundestag, 25th session, 17th legislative period	Deutscher Bundestag: Stenografischer Bericht 25.Sitzung, 17. Wahlperiode
D36	23/03/2010	Legislative drafts by the CDU/CSU and FDP: Draft of a legislation for the revision of the Renewable Energy Sources Act	Gesetzentwurf der Fraktionen der CDU/CSU und FDP: Entwurf eines. . .Gesetzes zur Änderung des Erneuerbare-Energien-Gesetzes
D37	25/03/2010	Protocol of the German Bundestag, 34th session, 17th legislative period	Deutscher Bundestag: Stenografischer Bericht 34. Sitzung, 17. Wahlperiode
D38	19/04/2010	Reponses by the technical expert Philippe Welter on the list of questions handed in by the parliamentary groups as part of the public hearing of the German parliament – committee for the Environment, Nature Conservation and Nuclear Safety – on the legislative draft by the CDU/CSU and FDP for the revision of the Renewable Energy Sources Act	Antworten vom Sachverständigen Philippe Welter auf die Fragen des Fragenkatalogs der Fraktionen im Rahmen der Öffentlichen Anhörung des Deutschen Bundestages – Ausschuss für Umwelt, Naturschutz und Reaktorsicherheit – zum Gesetzentwurf der Fraktionen der CDU/CSU und FDP zur Änderung des Erneuerbare-Energien-Gesetz
D39	19/04/2010	Reponses by the technical expert Dr. Wolfgang Seeliger on the list of questions handed in by the parliamentary groups as part of the public hearing of the German parliament – committee for the Environment, Nature Conservation and Nuclear Safety – on the legislative draft by the CDU/CSU and FDP for the revision of the Renewable Energy Sources Act	Antworten vom Sachverständigen Dr. Wolfgang Seeliger auf die Fragen des Fragenkatalogs der Fraktionen im Rahmen der Öffentlichen Anhörung des Deutschen Bundestages – Ausschuss für Umwelt, Naturschutz und Reaktorsicherheit – zum Gesetzentwurf der Fraktionen der CDU/CSU und FDP zur Änderung des Erneuerbare-Energien-Gesetz
D40	20/04/2010	Comments by the technical expert Prof. Eicke R. Weber on the public hearing on the legislative draft by the CDU/CSU and FDP for the revision of the Renewable Energy Sources Act in the committee for the Environment, Nature Conservation and Nuclear Safety of the German parliament	Stellungnahme von Prof. Eicke R. Weber zur Öffentliche Anhörung zum Gesetzentwurf der Fraktionen der CDU/CSU und FDP eines Gesetzes zur Änderung des Erneuerbare-Energien-Gesetzes des Ausschuss für Umwelt, Naturschutz und Reaktorsicherheit des deutschen Bundestag
D41	21/04/2010	Committee for the Environment, Nature Conservation and Nuclear Safety: Corrected protocol of the public hearing on the legislative draft by the CDU/CSU and FDP for the revision of the Renewable Energy Sources Act	Ausschuss für Umwelt, Naturschutz und Reaktorsicherheit: Korrigiertes Wortprotokoll Öffentliche Anhörung zum Gesetzentwurf der Fraktionen der CDU/CSU und FDP Entwurf eines . . . Gesetzes zur Änderung des Erneuerbare-Energien-Gesetzes
D42	05/05/2010	Legislative petition by the Green Party on the third consultation of the legislative draft by the CDU/CSU and FDP: Draft of a law for the revision of the Renewable Energy Sources Act	Entschließungsantrag der Fraktion BÜNDNIS 90/DIE GRÜNEN zu der dritten Beratung des Gesetzentwurfs der Fraktionen der CDU/CSU und FDP: Entwurf eines . . . Gesetzes zur Änderung des Erneuerbare-Energien-Gesetzes
D43	06/05/2010	Protocol of the German Bundestag, 40th session, 17th legislative period	Deutscher Bundestag: Stenografischer Bericht 40. Sitzung, 17. Wahlperiode
D44	08/06/2010	Briefing by the German government: Law for the revision of the Renewable Energy Sources Act, call for the conciliation committee	Unterrichtung durch den Bundesrat: . . . Gesetz zur Änderung des Erneuerbare-Energien-Gesetzes, Anrufung des Vermittlungsausschusses

Table A.1 (*Continued*)

ID	Date	Translated document title	Original title
D45	07/07/2010	Committee for the Environment, Nature Conservation and Nuclear Safety: Corrected protocol of the public hearing on the legislative draft by the Green Party: Accelerating the nuclear phase-out – Shaping the electricity market in a forward-looking way	Ausschuss für Umwelt, Naturschutz und Reaktorsicherheit: Korrigiertes Wortprotokoll Öffentliche Anhörung zum Antrag der Fraktion BÜNDNIS 90/DIE GRÜNEN: Atomausstieg beschleunigen – Strommarkt zukunftsfähig entwickeln
D46	11/08/2010	First legislation for the amendment of the Renewable Energy Sources Act	Erstes Gesetz zur Änderung des Erneuerbare-Energien-Gesetzes
D47	28/10 2010	Protocol of the German Bundestag, 68th session, 17th legislative period	Deutscher Bundestag: Stenografischer Bericht 68. Sitzung, 17. Wahlperiode
D48	01/12/2010	Protocol of the German Bundestag, 77th session, 17th legislative period	Deutscher Bundestag: Stenografischer Bericht 77. Sitzung, 17. Wahlperiode
D49	18/02/2011	Briefing by the German government: Report by the Expert Advisory Board on Environmental Issues: Pathways to 100% electricity generation from renewable energy	Unterrichtung durch die Bundesregierung: Sondergutachten des Sachverständigenrates für Umweltfragen: Wege zur 100% erneuerbaren Stromversorgung
D50	23/02/2011	Proposed resolution and report by the committee for the Environment, Nature Conservation and Nuclear Safety on the legislative draft by the German government: Draft of a legislation for the implementation of directive 2009/38/EG on the support of the use of energy from renewable sources (EAG EE)	Beschlussempfehlung und Bericht des Ausschusses für Umwelt, Naturschutz und Reaktorsicherheit zu dem Gesetzentwurf der Bundesregierung: Entwurf eines Gesetzes zur Umsetzung der Richtlinie 2009/28/EG zur Förderung der Nutzung von Energie aus erneuerbaren Quellen (Europarechtsanpassungsgesetz Erneuerbare Energien – EAG EE)
D51	24/02/2011	Protocol of the German Bundestag, 93rd session, 17th legislative period	Deutscher Bundestag: Stenografischer Bericht 93. Sitzung, 17. Wahlperiode
D52	23/03/2011	Legislative petition of the SPD: On the way toward a sustainable, efficient, affordable and secure energy system	Antrag der Fraktion der SPD: Auf dem Weg zu einem nachhaltigen, effizienten, bezahlbaren und sicheren Energiesystem
D53	01/05/2011	Legislation for the implementation of directive 2009/38/EG on the support of the use of energy from renewable sources (EAG EE)	Gesetz zur Umsetzung der Richtlinie 2009/28/EG zur Förderung der Nutzung von Energie aus erneuerbaren Energien (Eroparechtsanpassungsgesetz Erneuerbare Energien – EAG EE)
D53	06/05/2011	Experience report 2011 on the Renewable Energy Sources Act (EEG experience report)	Erfahrungsbericht 2011 zum Erneuerbare-Energien-Gesetz (EEG-Erfahrungsbericht)
D54	08/06/2011	Committee for the Environment, Nature Conservation and Nuclear Safety: Uncorrected protocol public hearing on "Support of renewable energies/energy transformation"	Ausschuss für Umwelt, Naturschutz und Reaktorsicherheit: Unkorrigiertes Stenografisches Protokoll: Öffentliche Anhörung zum Thema „Ausbau der erneuerbaren Energien/Energiewende"
D55	29/06/2011	Proposed resolution and report by the committee for the Environment, Nature Conservation and Nuclear Safety on the legislative draft by the German government for the revision of the law to support the electricity generation from renewable energies	Beschlussempfehlung und Bericht des Ausschusses für Umwelt, Naturschutz und Reaktorsicherheit zu dem Gesetzentwurf der Bundesregierung zur Neuregelung des Rechtsrahmens für die Förderung der Stromerzeugung aus erneuerbaren Energien
D56	30/06/2011	Protocol of the German Bundestag, 117th session, 17th legislative period	Deutscher Bundestag: Stenografischer Bericht 117. Sitzung, 17. Wahlperiode
D57	01/01/2012	Law for the preferential Feed-in of Renewable Energies (Renewable Energy Sources Act – EEG)	Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz – EEG)

Table A.2
Prevalence of issues over time.[a]

No.	Issue category	# text elements	Phase 1						Phase 2				Phase 3							Phase 4
			<1995	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	Lack of maturity and high cost of PV technology	73	19	12	14							2	2		3	5	4	2	5	5
2	Lack of mass market for solar PV	35	12	10	13															
3	Insufficient financial incentive for power producers of PV	89	51	7	17	6		1				2	5							
4	Market power of large utilities	60	6	8	13	4						2			3	4	7	2	9	2
5	Market support as chance to build PV industry and create jobs	371	20	37	31	3		4	1		4	18	9	4	31	57	82	11	38	21
6	Market support as chance to increase exports	108		2	5	1					1	7	1	1	5	40	30	4	10	4

Table A.2 (*Continued*)

No.	Issue category	# text elements	Phase 1						Phase 2				Phase 3							Phase 4
			<1995	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
7	High cost for energy-intensive industry	88										4	4		12	18	13		6	32
8	High cost for society and rising electricity prices	366		2	9							11	4		22	22	42	5	146	103
9	Increasing competition from China	76															4	2	63	7
10	Excess remuneration and windfall profits for PV industry	191														1	5	4	139	42
11	Risk of losing public acceptance for policy and technology	40													1		1		27	11
12	Risk of hurting domestic PV industry	234														1	2	2	205	24
13	Increased power intermittency and power regulation	191	9	2								4	2	1		12	15	2	35	109
14	Risk of reduced grid stability	262		1								4				7	18	4	90	138
15	Lack of market integration	166														1	17	3	13	132

[a] Note that the length and nature of the identified text elements varies. The count of elements is therefore intended to reveal general trends in issue prevalence rather than their exact importance in a particular year.

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