Responsive feed-in tariff adjustment to dynamic technology development

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Abstract

This paper reviews the adjustments of the feed-in tariff for new solar photovoltaics (PV) installations in Germany. As PV system prices have declined rapidly since 2009, the German government implemented automatic mechanisms to adjust the support level for new installations in response to deployment volumes. This paper develops an analytic model to simulate weekly installations of PV systems up to 30 kW (31% market share in 2011) based on project profitability and duration. The model accurately replicates observed market developments and is used to assess different adjustment mechanisms against multiple scenarios for PV system price developments. The analysis shows that responsive feed-in tariff schemes with frequent tariff adjustments and short qualifying periods reach deployment targets most effectively.

JEL Classification: O30, O31, Q42, Q48, C60.

Keywords: feed-in tariff, photovoltaic, renewable deployment.

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1 Introduction

Feed-in tariffs are the most common policy instrument worldwide to support renewable electricity, having been implemented by 65 countries and 27 states/provinces (REN21, 2012). In Europe, 21 out of 27 EU member states used feed-in tariff schemes as major support instruments in 2011 (Kitzing et al., 2012). Feed-in tariffs have become increasingly attractive as the guaranteed off-take price facilitates low-cost financing and administrative procedures for renewable energy deployment.

However, in recent years photovoltaics (PV) system prices declined significantly faster than expected, thereby increasing profitability for investors and triggering large investment volumes exceeding governments’ annual deployment targets. This raised concerns about the continued suitability of feed-in tariffs.

The German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) guarantees technology-specific tariffs for electricity feed-in generated by renewable energies. These tariffs are differentiated by energy source (solar, wind, etc.) and provide a purchase guarantee for a contracted time period (usually 20 years). The respective feed-in tariff levels are reduced by specific degression rates and reviewed every three or four years to ensure that renewable energy technologies will ultimately become competitive with conventional energy forms.

In Germany, PV feed-in tariff levels and degression rates were revisited every four years until 2009. Since 2009, deployment volumes significantly exceeded target volumes, turning Germany into the largest PV market in the world during 2009 and 2010 (accounting for 27% of global cumulative PV installations in 2011). This is seen as a challenge, as the higher volumes increase the policy costs borne by electricity consumers. Therefore, an automatic adjustment mechanism dependent on ongoing deployment volumes was introduced in 2009 in order to match PV system price reductions, followed by further adjustments to the mechanism in 2010 and 2011. Nevertheless, the deployment volume again reached 7.5 GW of new PV capacity in 2011 (see Figure 1.1). This raises the question, whether feed-in tariffs are compatible with policy objectives formulated as investment volumes in specific renewable energy technologies? The German National Renewable Energy Action Plan (Bundesrepublik Deutschland, 2010) defines a deployment target of 52 gigawatts (GW) installed PV capacity in 2020. The newly agreed version on the amended Renewable Energy Sources Act (EEG 2012) from June 2012 defines an annual target corridor between 2.5 GW and 3.5 GW for new PV installations.

With regard to Germany’s feed-in tariff degression framework, Kreyzik et al. (2011, page 17) find that “uncertainties still remain over whether responsive degression frameworks can control policy costs to the degree desired by policymakers”. This paper therefore analyzes the recent market evolution with an analytic framework that allows for the disentanglement of the various drivers of this development.

The analytic model introduced in this paper simulates the evolution of new PV installations and feed-in tariffs for systems up to 30 kW on the basis of observed PV system prices. This model is based on only three factors: (i) deployment increases proportionately with project profitability; (ii) profit expectations
of investors decreased after the Fukushima nuclear disaster in March 2011; and (iii) in periods prior to feed-in tariff reductions, projects are implemented more quickly in order to still receive the higher tariff levels.

The experience of the last years shows that deployment volumes can be explained by these simple factors. Therefore, the model is used to test five policy design proposals against different price scenarios in order to systematically define appropriate PV feed-in tariff adjustment parameters. Model results show that responsive feed-in tariff mechanisms with frequent tariff adjustments and short qualifying periods reach deployment targets effectively for small-scale systems with short project durations.

The paper complements previous analysis of feed-in tariffs. Haas et al. (2011) find that well-designed (dynamic) feed-in tariff systems are preferable to national green certificate trading schemes, as they are easy to implement and administration costs are usually lower, amongst other reasons. By comparing feed-in tariff, quota and auction mechanisms to support wind energy development in the UK and Germany, Butler and Neuhoff (2008) show that the German feed-in tariff in practice resulted in more deployment and lower prices paid per wind power delivered. Bürer and Wüstenhagen (2009) focus on private investors in innovative clean energy technology firms, and show that they perceived feed-in tariffs to be the most effective renewable energy policy. According to the European Commission, “well-adapted feed in tariff regimes are generally the most efficient and effective support schemes for promoting renewable electricity” (Commission of the European Communities, 2008, page 3). Couture and Gagnon (2010) provide an overview of different feed-in tariff remuneration schemes and conclude that market-independent, fixed price models (like the German feed-in tariff) create greater investment security and lead to lower-cost renewable energy deployment than market-dependent options.

**Figure 1.1: Annual PV installations in Germany 2000-2011, with targets until 2020**

Sources: Data from BMU (2012) and Bundesrepublik Deutschland (2010).
In the following, Section 2 traces the historic evolution of PV system prices and support level adjustments in Germany, and shows the responsiveness of PV deployment to feed-in tariff levels. Section 3 provides an analytic framework to explain the drivers for the observed behavior. Section 4 uses this framework to assess different policy design options under various price scenarios. Section 5 concludes the paper with a recap of findings.

2 PV technology development and feed-in tariff adjustment

2.1 Historic evolution of PV system prices

PV system prices have undergone a surprisingly rapid reduction since 2009. Figure 2.1 shows that prices for rooftop systems up to 100 kWp decreased by 64% in Germany over the last 6 years. The strong expansion of the global PV market resulted in accelerated system price declines since 2009: While the last 3 years depict the strongest annual price declines, prices show a record annual reduction by 27% during the most recent year (Q2 2011 until Q2 2012).

Figure 2.1: Average customer prices for installed rooftop PV systems up to 100 kWp

Data source: BSW-Solar (2012). Prices shown are without value added tax.

2.2 History of PV feed-in tariff adjustments in Germany

The Renewable Energy Sources Act (EEG) was established in Germany in 2000, succeeding the Electricity Feed-in Act from 1990. It regulates feed-in tariffs for renewable electricity generation. The feed-in tariffs within the EEG are differentiated by energy source (solar, wind, etc.), and are usually guaranteed for a period of 20 years. The respective tariff levels for new installations are traditionally reduced by annual degression rates and are reviewed every three or four years, thus creating the incentive for
manufacturers to improve technologies in order to ensure that renewables will become competitive with conventional electricity generation in the future.

In light of the dynamic cost developments of photovoltaics, anticipating PV system prices is increasingly challenging. If the degression rate is set above the innovation potential, feed-in tariffs may become too low to allow for an economic deployment of further renewable technologies. Given the share of the German market in the global situation, this was interpreted as a high risk for the further development of the technology and the industry. Setting degression rates too low can lead to windfall gains for manufacturers or project developers, and deployment volumes that exceed initial plans can cause significant cost increases.

The first PV feed-in tariff was established in 2000 at a rate of 0.99 DM/kWh (approximately 0.51 €/kWh), and the annual degression rate was originally set at five percent. Since 2004, tariffs have been graded according to system capacity and installation type (rooftop, façade, and free-standing installations), with rates between 0.46 and 0.62 €/kWh. From 2006 onwards, the annual degression rate for field installations increased to 6.5 percent. Since 2009, there are four tariff categories for rooftop installations (≤ 30 kW, 30-100 kW, 100-1000 kW, > 1000 kW), which were adjusted in June 2012 (≤ 10 kW, 10-40 kW, 40-1000 kW, 1-10 MW).

With the amendment of the EEG in October 2008 (EEG 2009), a “breathing cap” was introduced for new PV installations in order to allow the tariff level to respond to deployment volumes on an annual basis (annual 2009 target corridor: 1 to 1.5 GW). The EEG 2009 increased the annual base degression to eight percent for rooftop systems of up to 100 kW and to ten percent for other systems. Additionally, the degression rate should be either reduced or increased by one percent if PV deployment falls below or above the yearly target corridor.

In 2009, PV system prices declined by 26 percent (much more rapidly than originally expected), leading to total deployment of 3.8 GW. It became clear that the flexible degression adjustment was too weak. Therefore, the EEG was amended in August 2010, implementing additional tariff reductions between 8 and 13 percent on 1 July 2010, and three percent on 1 October 2010. The newly established degression system had the objective to deliver a target corridor of 2.5 to 3.5 GW annual installations. The base degression rate of 9 percent was set to increase by up to four percent if deployment exceeded this target volume. As annual PV installations amounted to 7.4 GW in 2010, feed-in tariffs were reduced accordingly by 13 percent on 1 January 2011.

The EEG Amendment from April 2011 implemented a new mechanism with the following biannual PV feed-in tariff adjustments dependent on the rate of deployment:

- On 1 July 2011 by up to 15 percent.\(^1\)
- On 1 January 2012 by a base degression of 9 percent, with an additional adjustment of between -7.5 and 15 percent. The possible annual degression rate could therefore be between 1.5 percent and 24 percent.\(^2\)

\(^1\) For ground-mounted systems on 1 September 2011.
However, this mechanism did not result in any degression in July and September 2011 (as less than 875 MW was installed between March and May 2011), and led to a 15 percent degression in January 2012 (as 5.2 GW were installed between October 2010 and September 2011).

The EEG 2012, passed by the Bundestag (Lower House of German Parliament) in June 2011, defined that the valid PV feed-in tariff degression scheme was to continue. According to the German Federal Network Agency (Bundesnetzagentur), Germany set a new monthly record of three GW installations in December 2011, resulting in 7.5 GW annual deployment in 2011. This motivated calls for further tariff adjustments. A draft version of a newly amended feed-in tariff mechanism was released in March 2012, but blocked in the Bundesrat (Upper House, representing the federal states) in May.

In June 2012 the German government finally released the agreed version on the revised PV feed-in tariff policy, including a one-off tariff reduction on 1 April 2012, ranging from 20 to 29 percent for new installations.\(^2\) Between May and October 2012, tariff levels are continuously reduced by 1% on a monthly basis. From November 2012 onwards, PV feed-in tariff degression levels depend on deployment, are adjusted every three months and implemented on a monthly basis.\(^3\) This adjustment mechanism aims to deliver an annual deployment corridor between 2.5 GW and 3.5 GW until 52 GW cumulative PV capacity will be reached.

### 2.3 Weekly PV deployment and market responsiveness

To improve monitoring of market development, since January 2009 new PV systems must be registered at the Federal Network Agency (Bundesnetzagentur). Although these systems are categorized according to their date of registration, and not their date of commissioning, the data allows for a realistic assessment of actual market volume (Reichmuth 2011).

Figure 2.2 shows weekly PV installations and feed-in tariff levels in Germany since January 2009. In periods prior to a reduction of the feed-in tariff, the volume of PV installations increased as house owners and project developers still wanted to benefit from the higher tariffs.

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\(^2\) When determining the new degression rate on 1 January 2012, the advanced “interim” degression from 1 July 2011 would be taken into account.

\(^3\) The law came into force on 1 April 2012. It includes new categories for rooftop systems, while ground-mounted systems receive a uniform tariff. Installations above 10 MW receive no further tariffs.

\(^4\) The adjustment of the feed-in tariff on 1 November 2012 depends on deployment in the period July until September 2012, projected on a yearly basis. The calculation of the degression levels from 1 February 2013 and 1 May 2013 onwards is based on the following qualifying periods: July until December 2012 and July 2012 until March 2013 respectively (projected on a yearly basis). From 1 August 2013 onwards, the degression will depend on deployment in the respective previous 12 months. The Federal Network Agency has one month to determine deployment and new feed-in tariff rates. If installations stay considerably below the target corridor, the degression will be paused or tariff levels will even be increased.
Figure 2.2: Weekly PV installations and feed-in tariff levels in Germany between January 2009 and May 2011

Installations based on data from Bundesnetzagentur.

These characteristic demand peaks can be observed in all relevant sub-categories, as shown in Figure 2.3. However, market responsiveness of these categories varies. Larger projects are usually more responsive to changing support schemes, if we compare PV deployment within the last week (or the last two weeks) before a feed-in tariff reduction to cumulative installations within the whole period of the same feed-in tariff levels. For instance, PV deployment was three times higher during the last two weeks of 2009 than the annual average for systems up to 30 kW, five times higher for systems between 30 and 100 kW, eight times higher for systems between 100 and 1000 kW, and seven times higher for installations above 1 MW.
This work focuses on the small-scale rooftop category up to 30 kW of the German PV feed-in tariff, as installations up to 30 kW accounted for 35% and 31% of total installations in Germany in 2010 and 2011 respectively. Weekly deployment of PV systems up to 30 kW is shown by the dark curve in Figure 2.3.

3 Analytic framework

The deployment effectiveness of a feed-in tariff scheme is analyzed using a simple model. The model depicts three factors impacting deployment. First, deployment increases proportionately with project profitability. Second, profit expectations of investors decreased after the Fukushima nuclear disaster in March 2011. Third, deployment is responsive to feed-in tariff changes. In periods prior to feed-in tariff reductions, project implementation accelerates to still receive the higher tariff levels.

3.1 Basic model

The basic model (without simulation of demand peaks) is as follows. We consider a discrete-time economy. At the beginning of every period $t$, each household decides whether to invest in a PV project, that would be finalized at date $t+d$, taking into account the average project duration $d$. PV installations $Y_{t+d}$ at time $t+d$ depend on profits $\pi_{t+d}$ according to the function
with parameters α and c. To account for increasing interest and changing profit expectations of households after the Fukushima nuclear disaster, both parameters α and c are determined for the periods before March and after April 2011.

Profits of PV projects are defined as net present value:

\[ \pi_{t+d} = v_{t+d} - p_t \]  

(2)

where \( p_t \) is the average system price at date \( t \) and \( v_{t+d} \) is the present value of the feed-in tariff at time \( t+d \).

The present value \( v_t \) of the feed-in tariff is given by the equation:

\[ v_t = f_t \cdot h \cdot \sum_{j=0}^{n} (1+i)^{-j}, \]  

(3)

where \( f_t \) is the feed-in tariff at date \( t \), \( h \) is the amount of full load hours per annum, \( n \) is the amount of years which the feed-in tariff is paid for, and \( i \) is the annual interest rate.

### 3.2 Advanced model with peak simulation

To account for the characteristic demand peaks of historic PV market evolution (see Figure 2.3), the basic model is extended as follows. The assumption is that, in periods before the feed-in tariff is reduced, investors make use of the flexibility to accelerate project execution so as to still qualify for the higher tariff levels. This market behavior then leads to the observed “clearance sale” effects. The representative investor choses the project duration \( d_t \) at time \( t \) according to the function

\[ d_t = \max l \]

subject to \( \pi_{t+l} \geq \pi_{t+d_{ave}} \)

\[ d_{min} \leq l \leq d_{ave}, \]

(4)

where \( d_{min} \) and \( d_{ave} \) are the minimum and average project duration respectively. While projects are usually implemented within the average duration, implementation accelerates in periods prior to feed-in tariff reductions.

Thus, the volume of PV installations at date \( t+d_{ave} \) is given by the equation:

\[ Y_{t+d_{ave}} = \sum_{l}^{d_{ave}} \left( \frac{\alpha \pi_{t+d_{ave}} - c}{\sum_{m=0}^{\infty} \alpha \pi_{t+m} - c} \right) \]  

(5)
4 Quantitative evaluation

4.1 Parameter choices

For the purpose of this model, a period \( t \) corresponds to one week. PV modules can achieve around 900 full load hours per year on average in Germany, and the feed-in tariff is paid for a time period of \( n=20 \) years. Annual interest rates \( i \) are based on monthly data published by Deutsche Bundesbank (2012).

The overall process duration of PV projects depends on system sizes. In Germany, according to the PV LEGAL project (PV LEGAL 2011), it varies between 3 to 8 weeks (6 weeks on average) for small-scale installations on residential buildings, 6 to 24 weeks (12 weeks on average) for small to medium-scale installations on commercial buildings, and 53 to 132 weeks (85 weeks on average) for medium to large-scale ground-mounted installations on open lands. To calculate profits of small-scale rooftop systems, the model uses their average project duration of 6 weeks.

The analytic framework is based on price and interest rates data that was available in summer 2012. BSW-Solar (2012) provides quarterly PV system price data (Q4 2008 – Q2 2012) for installations \( \leq 100 \) kW. In the model, this reflects the price within the middle of each quarter, the weekly price data for the intermediary weeks is linearly approximated. To use price data for systems \( \leq 30 \) kW, the data (which is reported for installations \( \leq 100 \) kW) is adjusted with a fixed shift factor.\(^5\) The evolution of profits, as well as system prices and present values of feed-in tariffs, is shown in Figure 4.1.

Figure 4.1: PV feed-in tariff, system prices, and profits for solar panels of up to 30 kW in Germany between January 2009 and December 2011

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\(^5\) This shift factor is calculated from monthly system price data (0-10 kW and 10-30 kW, June 2009 – May 2011) from Photon (2010, 2011) and based on installation data (2009-2010) from Reichmuth (2011, Figure 1-4).
To analyze the first two factors (see section 3), Figure 4.2 shows the relationship between historic PV installations and profits (margins to cover risks like e.g. the failure of components during 20 years lifetime). The amount of weekly installations largely increases with rising profits. However, there are several outliers, which represent “clearance sale” effects in weeks before the feed-in tariff was reduced. Moreover, this figure illustrates that the relationship between installations and profits has shifted over time. Compared to the period before the Fukushima nuclear disaster, lower margins are needed for the same amount of installations from April 2011 onwards. Environmental awareness and motivation of households to invest into clean energy sources seem to have clearly increased thereafter. A maturing market with increasing experience and decreasing risk for project developers might be further reasons for this shifting behavior over time. These observations validate the first two factors of the model.

**Figure 4.2: Weekly PV installations and profits for systems of up to 30 kW in Germany, 2009-2011**

The analytic framework assumes a linear correlation between weekly installations and profits in Germany. By adjusting for changing investment behavior and maturing market conditions before and following the Fukushima disaster, estimations lead to the parameters $\alpha_1=0.06$ and $c_1=55.86$ for January 2009 until March 2011, as well as $\alpha_2=0.08$ and $c_2=43.11$ for April 2011 until December 2011. The post-Fukushima correlation between installations and project profitability is assumed to stay constant in later periods.

Based on these parameters, Figure 4.3 shows the resulting evolution of PV installations according to the basic model (see section 3.1).
The basic model delivers a relatively realistic match of historic and model-based installations. However, the largest deviation to historic PV deployment are the demand peaks observed in periods before feed-in tariff reductions. The advanced model (see section 3.2) is used to simulate these peaks.

As mentioned above, the overall process duration of PV projects in Germany varies between 3 to 8 weeks (6 weeks on average) for small-scale installations on residential buildings. The basic model uses the average project duration of 6 weeks to calculate profits of roof-top systems of up to 30 kW. However, project developers have an interest in accelerating the implementation process in periods prior to feed-in tariff reductions. Therefore projects which are started 3 to 5 weeks before a feed-in tariff reduction are implemented more rapidly, so as to be completed in the last week before the tariff cut. In the next sections, this advanced model is used to simulate PV deployment between January 2009 and December 2014 for different feed-in tariff designs and system price scenarios.

### 4.2 Model results for the current adjustment mechanism

In this section, the advanced model (see section 3.2) is used to simulate weekly PV deployment for the feed-in tariff adjustment mechanism that was implemented in June 2012 (as described in section 2.2). The model calculations of the feed-in tariff levels from January 2012 onwards use rooftop systems of up to 30 kW as representative category. As the feed-in tariff adjustment is formulated based on total deployment volume, the model assumes that the market share of projects of up to 30 kW (31% in 2011) stays constant. Feed-in tariff rates for systems up to 30 kW from April 2012 onwards are calculated as average rates between the tariff levels of the newly implemented size categories for systems up to 10 kW and up to 40 kW respectively (see section 2.2). To simulate PV installations from January 2012
onwards, the model uses observed system price data until Q2 2012 from BSW-Solar (2012), and assumes a further yearly continuous price decline by 16% (equal to average price decrease over the last 6 years).

In comparison to the basic model, the advanced model is able to simulate PV deployment with its characteristic demand peaks. Figure 4.4 shows that historic and model-based PV installations match fairly well.

**Figure 4.4: Historic and model-based weekly PV installations (advanced model) for systems of up to 30 kW**

There was no feed-in tariff reduction on 1 July (and 1 September) 2011, as less than 875 MW of PV systems were registered at the Federal Network Agency between March and May 2011. However, market demand peaked before July 2011, due to temporary uncertainty about potential tariff cuts. On 1 January 2012 the degression amounted to 15%, as 5.2 GW were registered between October 2010 and September 2011.

When comparing historic and model-based deployment, we observe that historic demand peaks are higher in summer 2010 and 2011, and lower at the end of each year. These seasonal peak variations can be explained by weather conditions and holidays at the end of the year making project implementation more difficult.

### 4.3 Model results for alternative design options

In 2011 and 2012, alternative options for the design of the PV feed-in tariff adjustment mechanisms were brought forward by different political parties. Several design options are assessed in this section.
with the quantitative model previously introduced. In particular, the focus of this analysis is on the impact of the following variables:

- degression frequency;
- adjustment flexibility; and
- qualifying period.

Table 4.1 defines five different design options with their respective parameters. These design choices contain monthly and quarterly degression frequencies, with adjustment rates being either fixed (like in the proposal of the Social Democratic Party from December 2010), or dependent on installations in previous months, and in the latter case with qualifying periods of either 3 months (similar to the proposal of the Green Party from February 2011), or 12 months.

<table>
<thead>
<tr>
<th>Name</th>
<th>Dm P3</th>
<th>Dm P12</th>
<th>Dq P3</th>
<th>Dq P12</th>
<th>Df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degression frequency</td>
<td>monthly</td>
<td>Monthly</td>
<td>Quarterly</td>
<td>quarterly</td>
<td>quarterly</td>
</tr>
<tr>
<td>Basic degression</td>
<td>1%</td>
<td>1%</td>
<td>2.97%</td>
<td>2.97%</td>
<td>4%</td>
</tr>
<tr>
<td>Degression corridor</td>
<td>-1.5% (p.q.) – 2.8% (p.m.)</td>
<td>-1.5% (p.q.) – 2.8% (p.m.)</td>
<td>-1.5% - 8.17%</td>
<td>-1.5% - 8.17%</td>
<td>-</td>
</tr>
<tr>
<td>Qualifying period</td>
<td>3 months</td>
<td>12 months</td>
<td>3 months</td>
<td>12 months</td>
<td>-</td>
</tr>
</tbody>
</table>

The “Dm P3” and “Dm P12” designs contain a monthly 1% degression, which can vary between 0% (–1.5% each quarter) and 2.8% depending upon the amount of installations during the previous 3 and 12 months, respectively. Degression rates are calculated and implemented each month, compared to the current feed-in tariff design with quarterly determinations and monthly implementations. The “Dq P3” and “Dq P12” designs use a quarterly frequency with a basic 2.97% degression (which corresponds on a yearly basis to a monthly 1% degression). As there is a time lag of one month between qualifying periods and corresponding degression dates in the adjustment design currently in place, the same is implemented in all four flexible design options in Table 4.1. The “Df” design includes a fixed quarterly 4% degression.

Figure 4.5 shows the evolution of model-based PV feed-in tariffs (for systems up to 30 kW) for all feed-in tariff design options in the period January 2012 – December 2014. To calculate feed-in tariff levels from 2012 onwards for the flexible adjustment designs with their different qualifying periods (see Table 4.1),
the model assumes that deployment in 2011 corresponded to the 3 GW annual target corridor (with 250 MW monthly installations).6

Figure 4.5: PV feed-in tariff rates for systems of up to 30 kW for different adjustment design options

The newly implemented feed-in tariff scheme ("EEG new") includes a one-off tariff reduction in April 2012, ranging from 20% (up to 10 kW) to 24% (up to 30 kW) for small-scale PV systems. After fixed monthly 1% degression rates between May and October 2012, the model-based feed-in tariff level increases by 1.5% in November 2012 and February 2013 (since installations in the respective qualifying periods are below 1 GW on a yearly projected basis), and decreases again from May 2013 onwards with changing degression levels.

The “Dm P12” design option with monthly degressions and a qualifying period of 12 months reaches the lowest tariff level (14.75 ct/kWh) at the end of 2014. The design options with qualifying periods of 3 months show relatively high degression rates in 2012, and converge towards the basic monthly (1%) and quarterly (2.97%) degressions from June (Dm P3) and July (Dq P3) 2013 onwards respectively. The differentiation between monthly and quarterly degression frequencies has a relatively low impact on the long-term evolution of tariffs, given a continuous decline of system prices. The fixed “Df” design leads to the highest tariff rates from August 2012 onwards, resulting in levels at the end of 2014 being 5% larger than under the “Dm P12” design.

According to the newly amended Renewable Energy Sources Act (EEG) of June 2012, the future target corridor for supported PV installations amounts to 2.5 to 3.5 GW per year. Assuming that the 31%  

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6This assumption is implemented to avoid that the record month of December 2011 with its 3 GW of solar installations has a relatively long impact within the feed-in tariff calculations of the adjustment design options with qualifying periods of 12 months.
market share of small-scale systems up to 30 kW in 2011 will stay constant in the future, this corresponds to a quarterly target corridor of 194 to 271 MW for these installations. Figure 4.6 shows historic and model-based installations for the different feed-in tariff adjustment designs on a quarterly basis for the simulated period 2012 until 2014, as well as the respective target corridor.

Figure 4.6: Quarterly PV installations up to 30 kW for different feed-in tariff designs and target corridor

Following the strong one-off tariff reduction in April 2012, historic PV installations in the second quarter of 2012 decreased less than model-based deployment under the current feed-in tariff adjustment mechanism. This can be explained by the retrospective nature of this one-off adjustment. While it had already been announced in February 2012, the German Parliament finally approved an amended version only in June 2012, leading to investment uncertainty during the legislative process. Thereafter, model-based installations grow steadily for this design option to reach the target corridor in Q1 2013 and to converge there from Q2 2014 onwards.

After a certain adjustment period, the feed-in tariff designs with qualifying periods of 3 months are able to reach the targeted installations corridor from Q2 2013 onwards. In comparison, adjustment schemes with qualifying periods of 12 months lead to more deployment in 2012, but fall below the target corridor between mid 2013 and the end of 2014. Installations under the fixed degression design always exceed the target corridor.

However, the future price development is not known at the time of decisions on the adjustment mechanism. Therefore, the designs need to be tested against different potential scenarios. The evolution of PV system prices from Q2 2012 onwards is difficult to predict. First, because there are
global production capacities for around 50 GW new PV modules\(^7\), which are often under used. Second, because demand for PV modules depends on the evolution of feed-in tariffs and other policy schemes in many countries, and is difficult to predict.

This analysis uses the following scenarios for the evolution of system prices for small-scale PV installations in Germany. Figure 4.7 shows the respective prices in all scenarios in the simulation period.

**Business-As-Usual (BAU) scenario:** The price continuously declines from Q2 2012 onwards by yearly 16 percent (average during last 6 years, as defined in section 4.2).

**Reference (REF) scenario:** To allow for a detailed assessment of convergence of the deployment volume to target levels after unexpected changes of PV system prices, a reference scenario is defined which ensures that the installations volume matches the target deployment (18 MW per week for systems up to 30 kW). The starting price is calibrated to ensure the adjustment model meets the deployment trajectory in Q1 2012.\(^8\) The price then continuously declines from 19 February 2012 onwards at an annual rate of 16 percent.

**Jump 1 (J1) scenario:** The price evolves as in the REF scenario, with a one-off price reduction of 15 percent on 1 January 2013.

**Jump 2 (J2) scenario:** The price evolves as in the J1 scenario, with a one-off price increase of 10 percent on 1 January 2014.

**Figure 4.7: PV system prices for installations up to 30 kWp in model scenarios**

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\(^7\) According to Sarasin (2011), there are 21 GW of demand and around 50 GW of production capacity for solar modules at the end of 2011.

\(^8\) The corresponding price level is calculated as 2408 €/kW, being fixed in the period 20 November 2011 until 18 February 2012.
While the “Df” feed-in tariff design includes fixed 4% reductions every three months, feed-in tariff cuts in the flexible adjustment designs depend on the amount of PV capacity installed in the previous months, and thereby differ in the respective system price scenarios. Table 4.2 summarizes model-based feed-in tariff rates for all adjustment designs in the different price scenarios. While the “Dm P12” design leads to the lowest feed-in tariff at the end of 2014 in the BAU and J1 scenarios, the “Dq P12” and “Df” designs reach the lowest levels in the J2 and REF scenarios respectively. With regard to the flexible design options, the “Dq P3” design results in the highest tariff rates at the end of the simulation period in all scenarios.

Table 4.2: Feed-in tariff rates [ct/kWh] for systems up to 30 kW at the end of 2012 and 2013 for different adjustment design options and price scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year</th>
<th>Feed-in tariff design</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Dm P3</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>16.83</td>
</tr>
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Mitchell et al. (2011, p. 883) define policy effectiveness as “the extent to which intended objectives are met, for instance the actual increase in the amount of RE electricity generated or share of RE in total energy supply within a specified time period”. In the following, the focus is on the effectiveness of the different PV feed-in tariff design options as the extent to which the annual target corridor between 2.5 and 3.5 GW of installations is met.

The target corridor for systems up to 30 kW, assuming that they continue to constitute 31% of the market (as in 2011), corresponds to a deployment volume between 775 and 1085 MW on a yearly basis, and between 194 to 271 MW on a quarterly basis respectively. Figures 4.8, 4.9 and 4.10 show the respective deployment levels for price scenarios REF, J1 and J2.
In the reference scenario, both feed-in tariff designs with quarterly degression adjustments lead to quarterly deployment permanently matching the target corridor. Installations for both monthly adjustment designs fall below the target corridor at the beginning of the simulation period, as system prices are fixed for one quarter while feed-in tariffs decrease every month. In response, degressions temporarily decrease to 0.75% per month, until deployment reaches the target corridor again. Under the fixed tariff scheme deployment continuously decreases as the support level declines faster than system prices.

The abrupt price reduction in January 2013 in the J1 scenario leads to a strong deployment increase for all feed-in tariff design options. Accordingly, degression levels increase within the flexible adjustment schemes, so that from mid 2013 onwards all mechanisms result in decreasing quarterly installations again. The degression schemes with qualifying periods of 3 months are fastest in correcting the excess deployment and converge within the target corridor from 2014 onwards. In contrast, the design options with longer qualifying periods take longer to revert to the target corridor and subsequently undershoot.
In the second price jump scenario, quarterly installations for all adjustment mechanisms fall below the target range at the beginning of 2014. The design options with qualifying periods of 3 months are again quickest in recovering deployment again, and are the only mechanisms to finally reach the target corridor at the end of the simulation period. Because of their long qualifying periods, the other flexible schemes are relatively slow in responding to quickly changing PV system prices.

5 Conclusion

This paper reviews the experience with the adjustments of the feed-in tariff scheme for solar photovoltaics in Germany. The National Renewable Energy Action Plan of the German government targets the installation of 52 GW of PV power generation capacity in Germany by 2020. The amended Renewable Energy Sources Act (EEG) from June 2012 defines a yearly target corridor between 2.5 GW and 3.5 GW for new PV installations. However, in both 2010 and 2011 yearly PV deployment was around 7.5 GW.

This shows that setting appropriate levels for feed-in tariffs is a challenge, especially as PV system prices decreased faster than expected since 2009. Thereafter, the feed-in tariff for new installations was adjusted by several short-term political interventions. Despite the differences between these individual adjustments, the market responded in a similar manner in all cases. In periods prior to feed-in tariff reductions the volume of installations always peaked as investors aimed to still qualify for the higher tariff levels. In this regard, larger projects are usually more responsive to changing support schemes. However, as small-scale PV installations of up to 30 kW account for a large share of total installations in Germany, and as they have relatively short planning and construction periods, this work focuses on the small-scale roof-top category of the German PV feed-in tariff.
The analytic model developed in this paper is able to simulate the evolution of new PV installations and feed-in tariffs on the basis of observed PV system prices. This simple model is based on only three factors: (i) deployment increases proportionately with project profitability; (ii) profit expectations of investors decreased after the Fukushima nuclear disaster in March 2011; and (iii) in periods preceding feed-in tariff reductions, projects are implemented faster to still qualify for the higher tariffs.

Model results show that demand responds very quickly (as project duration of small-scale PV systems is only six weeks on average) to declining system prices. Larger profitability leads to increasing installation numbers. The demand peaks result from accelerated projects that are completed in the week immediately prior to a feed-in tariff reduction. Overall, the simulated installation volumes closely match the observed weekly deployment numbers.

This suggests that the analytic framework has identified the main factors driving deployment choices. However, in the future or for other project sizes, investors might also respond to other factors changing deployment volumes, like uncertainty of policy development or a mobilizing effect if there are perceptions of a last opportunity to qualify for support. For the simulation of the coming years, the model assumes that the majority of investors will continue to realize projects because of prospective feed-in tariff support. However, in the case of further strong system price declines and following tariff reductions in the future, the share of projects without receiving feed-in tariffs might grow.

The analytic model allows for the analysis of feed-in tariff adjustment mechanisms with different degression frequencies, adjustment flexibilities, and qualifying periods. Thus, the model is used to simulate PV deployment and feed-in tariff levels for five policy design options in four PV system price scenarios. Model results show that responsive adjustment mechanisms of PV feed-in tariffs are suited to stabilize deployment and therefore avoid overfunding, provided that tariff adjustments are appropriately aligned with actual deployment. As forecasts for PV system prices are very uncertain, a rigid degression scheme is fraught with risk. Responsive adjustment schemes with high degression frequencies can avoid strong pull-forward effects in periods preceding tariff reductions. Flexible feed-in tariff designs with qualifying periods of 3 months are fastest in responding to quickly changing PV system prices.
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