

# Innovation of price adjustment mechanisms to support investment in solar power in Germany

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**Abstract.** It has been widely agreed that to incentivize renewables integration into the power system, not only pricing mechanisms, but price adjustment mechanisms have played a vital role, and it has been true for the German *Energiewende*. This study is to carry out a detailed analysis of investment results influenced by innovative price adjustment mechanisms from an auto degression rate to a feedback system. Employing linear regression models for the historical data of investment in small-scale rooftop PV projects in Germany, we have found out a better correlation between PV system price and feed-in tariff (92.09%) under quarter feedback and monthly adjustment mechanism compared to an annual feedback system. However, the underinvestment in recent years reveals that a feedback mechanism without specific mathematical shapes was not effective enough in term of meeting the targeted volume. Therefore, further researches are to design mathematical images of feedback mechanism in order to find out the trajectory of electricity price in the future which at the same time satisfies the target of investment and economic effectiveness.

## 1 Introduction

Energy transition is becoming a global trend of the electricity industry. Germany is one of the leaders of this movement which is considered as a successful pattern of integration of wind and solar into the power market [1]. Compared to the rest of the world, Germany started to immigrate renewables into the power system earlier. However, it took this country long time to prepare for the integration of solar PV. The year 1990 marked the first take-off for wind technology while after 1998, German people could see a kick off solar power [2]. After almost three decades, Germany owns more than 42 GW of solar power, accounts for 21% of total installation [BMW, 2018].

To encourage the sharing of solar power, a nation can put into use one of the three basic available pricing mechanisms including feed-in tariff, auction, CO<sub>2</sub> pricing, or combine them. A feed-in tariff is a system that the government decides price levels (price commitment to the producer) and the market sets quantities. In contrast, an auction is a pricing mechanism in which the amount of installed capacity, electricity generation, or budget is bided. Each auction volume type has advantages and disadvantages, however, installed capacity-based volume is more convenient for designing auctions [3]. Two main kinds of auction formats consist of sealed bid auctions and dynamic descending price auctions [4]. A carbon price is an amount that must be paid for the right to emit one tone of CO<sub>2</sub> into the atmosphere [IPCC, Glossary, 2007]. There are two main types of carbon pricing including emissions trading systems (ETS) and carbon taxes [WB]. An ETS or a cap-

and-trade system caps the total CO<sub>2</sub> emissions and allows to sell and buy. A CO<sub>2</sub> market is established based on this mechanism. A carbon tax sets a tax rate on CO<sub>2</sub> emission from fossil fuels use.

After the introduction of FIT for solar PV in 2000, the following years have seen the adjustment of FIT level to bring this price in line with technology cost changes [5] [6] [7] [8]. In order to reach a better control of renewables expansion, in 2015, a trial auction mechanism was introduced for ground-mounted PV [EEG 2014], and large roof-top mounted PV has been started to be applied this mechanism in 2017. For small and medium rooftop projects, project developers can choose one among three pricing mechanisms (FIT, FIP or auction) [EEG 2017] [9]. Recently, Germany has raised the idea and considered a price tag on CO<sub>2</sub> emission with the hope that it would be an option for “the second wave *Energiewende*” and push this country to get the aim of Climate Action Plan 2050 [Cleanenergywire].

Under the FIT mechanism, Germany was successful in encouraging private investment in renewables [10]. However, this price system did not expose investors to a price competition. The over an increase of capacity and generation did not achieve the lowest cost. In addition, the financial burden on consumers because of a higher RE surcharge has been one of the challenges [11]. Compared to the FIT, the auction mechanism which requires competitive pricing is expected to be a better tool to control the investment. Under this system, with given targets, the low-cost projects are favored and approved.

But whatever pricing mechanism is chosen, there is a key issue that needs to be addressed: the payment levels should be based on electricity generation cost. Over the last two decades, the world has seen a significant and fast reduction of photovoltaics technology costs [Bloomberg New Energy Finance, 2015]. Furthermore, forecasting the change level of technology cost is a tough task. In case of awarding excessive profits, the overinvestment will occur. In contrast, if the set price is lower than the expectation of investors, the target of investment will not be met. Therefore, it is extremely important to define a reasonable price adjustment method.

The present study was designed to investigate the impact of different price adjustment policies on the investment in solar power as well as the electricity bill in Germany. In section 2, we outline the linear regression models, input and output variables, the research scope, and an overview of solar power integration. Section 3 is to look at the impact of policy on the investment decision in small-scale solar power projects. Conclusions, policy implications and suggestion for future researches are given in section 4.

## 2 Analysis framework

Using linear regression models, we examine the effect of price adjustment mechanisms on the diffusion of solar power in Germany. We investigate the relationship between PV system price and FIT, the influence of profit on investment decision. Profitability can be measured through the value of net present value (NPV), or internal rate of return (IRR).

NPV is a measurement of profit calculated by subtracting the present values of cash outflows (including initial cost) from the present values of cash inflows over a period [Investopedia]. In other words, NPV calculation is a standard method to consider whether a potential investment project should be undertaken ( $NPV > 0$ ) or not ( $NPV \leq 0$ ). To compare the profitability over the years, we ignore the project scales and calculate NPV for one unit of investment.

$$NPV_t = \sum_{\tau=t}^n \frac{R_{\tau} - C_{\tau}}{(1+r)^{\tau}} - I_0 = \sum_{\tau=t}^n \frac{FLH_{\tau} * FIT_{\tau} - OM_{\tau}}{(1+r)^{\tau}} - I_0 \quad (1)$$

$NPV_t$ : net present value of 1 MW put into operation in the year t (million Euro/MW).

$I_0$ : specific investment cost of 1 MW put into operation in the year t (million Euro/MW).

$R_{\tau}, C_{\tau}$ : annual revenue, cost of 1MW in the year  $\tau$  (million Euro/MW/year).

$OM_{\tau}$ : annual operation and maintenance costs in the year  $\tau$  (million Euro/MW/year).

$FLH_{\tau}$ : full load hours in the year  $\tau$  (hours).

$FIT_t$ : feed – in tariff of projects put into operation in the year t (cents/kWh).

r: interest rate of projects put into operation in the year t (%).

IRR is a metric used in capital budgeting to estimate the profitability of potential investments [Investopedia]. IRR is a discount rate that makes NPV of all cash flows

from a particular project equal to zero. With a fixed interest rate, the higher IRR, the higher profitability. We invest in a project if  $IRR > r$ , and do not if  $IRR \leq r$ .

We investigate the effect of price adjustment mechanisms on the investment using the following functions:

$$\widehat{FIT}_t = \hat{\beta}_1 + \hat{\beta}_2 I_0 \quad (2)$$

$$\widehat{\Delta P}_t = \hat{\gamma}_1 + \hat{\gamma}_2 \pi_t \quad (3)$$

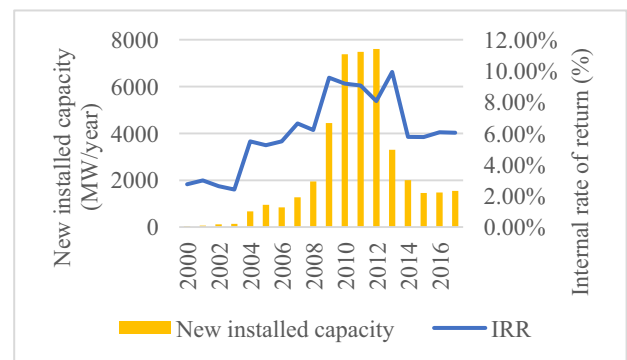
$\widehat{FIT}_t, \widehat{\Delta P}_t$ : estimated feed-in tariff, new installed capacity of projects put into operation in the year t.

$I_0, \pi_t$ : average PV system price, profitability (NPV or IRR) of projects put into operation in the year t.

$\hat{\beta}_1, \hat{\beta}_2, \hat{\gamma}_1, \hat{\gamma}_2$ : estimated parameters of models.

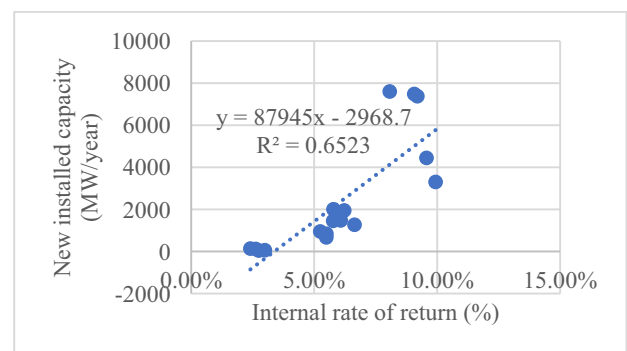
In order to estimate parameters, the historical data from 2000 are collected. Although the interest rates are different for project scales, investor types, for simplicity, we take 3.5% as the interest rate for solar power projects and remains unchanged [12]. Full-load hours are assumed at 1,000 hours/year and remained unchanged. Operation and maintenance cost is assumed to equal to 1% of investment cost.

The following parts are to illustrate the investment affected by profitability over last 28 years of solar power in Germany under the FIT mechanism.



**Fig 1.** Internal rate of return and annual installed capacity of solar power in Germany

The investors got higher profit between 2009 and 2013 at more than 9% of IRR and a stable rate in recent years at about 6% (Fig 1).



**Fig 2.** Correlation between internal rate of return and new investment in solar power in Germany

The linear regression function:  $\widehat{\Delta P}_t = 87,945IRR_t - 2,968$ ,  $R^2 = 65.23\%$ . Thus, 65.23% investment decision is explained by profitability (Fig 2).

### 3 Analysis the impact of price adjustment mechanisms on solar power investment in Germany

Currently, existing three kinds of pricing support mechanism includes FIT, FIP, and an auction in Germany. However, it is regulated that small-scale solar PV projects can choose to be paid FIT. For simplicity, this research takes the small-scale projects (up to 30 kWp until March 2012 and up to 10 since April 2012) for analyzing price adjustment mechanism under a FIT system.

In 2000, with the expected IRR at that time was approx. 5 – 7%, the FIT was set at 0.51 Euro cents/kWh for all kind of solar technology. In 2003, new rates were issued for varied sizes (small, medium and large) and technology (roof-mounted, ground-mounted). After many times of adjustment, the FIT mechanism has played a crucial role in the development of solar power. Designing the FIT mechanism, policymakers have to answer two basic questions: (1) which level the FIT should be set, and (2) how often the FIT should be adjusted. Obviously, the levels of FIT should be in line with the levelized cost of electricity (LCOE).

$$LCOE_t = \frac{I_0 + \sum_{\tau=t}^n \frac{C_\tau}{(1+IRR_t)^\tau}}{\sum_{\tau=t}^n \frac{E_\tau}{(1+IRR_t)^\tau}} = \frac{I_0 + \sum_{\tau=t}^n \frac{OM_\tau}{(1+IRR_t)^\tau}}{\sum_{\tau=t}^n \frac{FLH_\tau}{(1+IRR_t)^\tau}} \quad (4)$$

$LCOE_t$ : levelized cost of electricity of 1 MW put into operation in the year t (cents/kWh).

$IRR_t$ : internal rate of return of projects put into operation in the year t (%).

Secondly, the FIT adjustments should diminish the gap between the targeted installed capacity and actual investment. In general, the adjustment can be implemented on the time, or the quantity, or a combination of them. The following table illustrates the innovative methodologies to adjust FIT levels for solar PV in Germany.

**Table 1.** Alternative price adjustment mechanisms for solar power under the FIT regulation in Germany

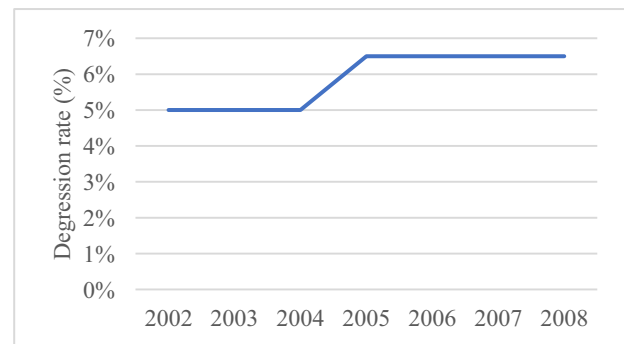
Method	Applied Time	Frequency of adjustment	Feedback
Pre-determined	2000 – 2008	Annually	No
Feedback mechanism	2009 – 03/2012	Annually	Annual feedback
Feedback mechanism	04/2012 – now	Monthly	Quarter feedback

Beginning with a predetermined reduction rate when solar panels were new and expensive technologies. Then, the feedback mechanism which based on responsive

information of actual investment was applied. Each mechanism is evaluated to be suitable for a certain phase of the diffusion. The following parts are to explain the adjustment mechanisms in a graphical way, simple mathematic equations based on the experience from the German Energiewende.

#### 3.1 Pre-regulated depression rate

Kicking off the photovoltaics integration in 2000, Germany introduced an annual reduction scheme of FIT levels. This method was employed until 2008 [EEG 2000, 2005].



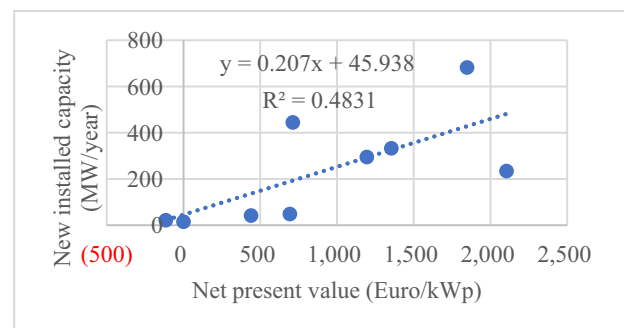
**Fig 3.** Annual depression rates of FIT for solar power in Germany between 2000 and 2008

The depression rate was 5%/year during the years 2002 to 2004, and 6.5%/year between 2005 and 2008. Under the pre-determined method, the adjustment FIT is defined with the following equation:

$$FIT_{t+1} = FIT_t(1 - d_{t+1}) \quad (5)$$

$FIT_t, FIT_{t+1}$ : FIT levels in the year t and t+1, respectively.

$d_{t+1} = f(\%I_{t+1})$ : depression rate of FIT in the year t+1 which is based on the prediction of PV system price reduction ( $\%I_{t+1}$ ). The larger reduction of forecasted PV system price is, the larger depression rate is.



**Fig 4.** Correlation between NPV and annual installed capacity of small scale solar power in Germany between 2000 and 2008

The linear regression function:  $\widehat{\Delta P}_t = 0.207NPV_t + 45.938$ ,  $R^2 = 48.31\%$ . Thus, 1 Euro/kWp increase in NPV led to 0.207 MW/year increase in installation. The number 45.938 reveals that during those years, investors expected to get a higher NPV in the following years. However, during this period, only 48.31% the change of

investment behavior was reflected by profitability (Fig 4).

### 3.2 Feedback mechanism

Because of a fast reduction of PV system cost, in 2009, a new degression scheme was adopted for photovoltaics based on feedback information of actual investment. With an annual given target of 2,500 MW/year and a prediction of PV system price reduction, a benchmark rate of degression was set at 9% in 2011 [EEG 2010]. It depends on the actual investment; the adjustment percentage can be lower or higher.

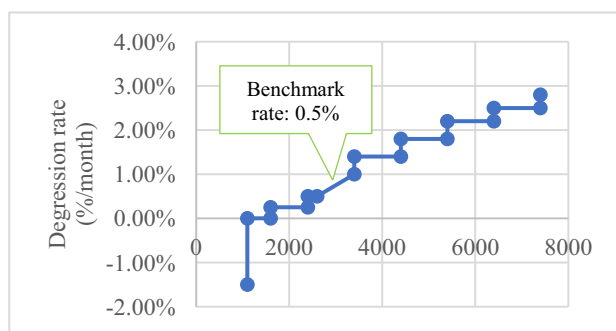
The FIT under the annual feedback mechanism is formulated as follows:

$$FIT_{t+1} = FIT_t(1 - d'_{t+1}) \quad (6)$$

$d'_{t+1} = f(\%I_{t+1}, \Delta P^t)$ : degression rate in the year t+1 not only depends on the prediction of PV system price reduction in the year t+1 ( $\%I_{t+1}$ ), but also the gap between the target and the actual investment in the year t ( $\Delta P^t = P_r^t - P_d^t$ ).  $P_r^t, P_d^t$  are registered and desired installation capacity in the year t, respectively.

However, due to an unexpected faster technology cost reduction, and deficiencies of the FIT-scheme of a) being updated only annually and b) the degression being too low, a massive overinvestment of solar power between 2009 and 2012 ensured. The actual investment was more than 7,000 MW/year while the targeted installed capacity was only between 2,400 and 2,600 MW/year. During this period, the investors attained high-profit margins, and the surcharge which had to be shouldered by the majority of private consumers rose to levels that became politically unbearable.

After realizing that the high FIT levels were inappropriate, Germany switched to a more frequent adjustment mechanism afterward (monthly adjustment with quarter year feedback information). According to the new law, if the registered capacity was between 2,400 and 2,600 MW in this year, the degression rate in the next period (next three months) would be 0.5%/month. The feedback qualitatively works like: the higher the installation, the higher the degression rate and inversely.



**Fig 5.** Monthly degression rate of FIT for solar power in Germany in 2014

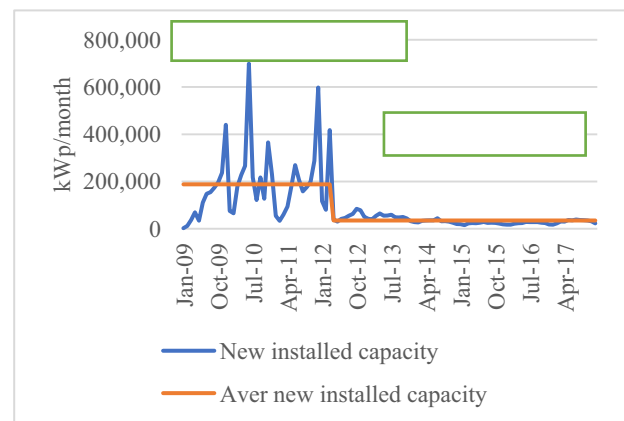
The equation of the mechanism is as follows:

$$FIT_{m+1} = FIT_m(1 - d''_{m+1}) \quad (7)$$

$FIT_m, FIT_{m+1}$ : FIT levels at the month m, m+1 (m is the last month of the previous adjustment quarter, m+1 is the first month of the next adjustment quarter) (m = 3, 6, 9, and 12).

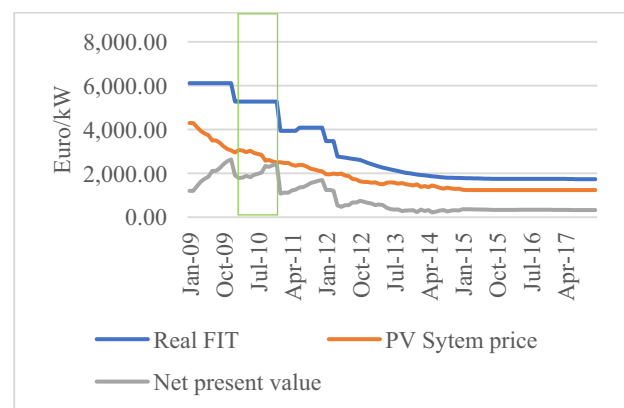
$d''_{m+1} = f(\%I_{m+1}, \Delta P^t)$ : degression rate at the month m+1 and two following months which not only depends on the expected PV system price reduction in the month m+1 ( $\%I_{m+1}$ ), but also the gap between the target and the actual investment in the year t ( $\Delta P^t = P_r^t - P_d^t$ ).  $P_r^t = a_m \sum_{k=1}^m P_r^k$ ,  $P_r^k$  is the registered capacity in the month k (k=1÷12),  $a_m = 4, 2, 4/3, 1$  corresponds to m = 3, 6, 9, 12.

Thus, instead of depending on the time, under the feedback mechanism, the degression rate relies more upon the volume of installation. In the following part, we will investigate the effect of annual and monthly FIT adjustment on the investment in small-scale PV projects.



**Fig 6.** Investment in small-scale solar power projects in Germany between Jan 2009 and Dec 2017

A significant lower average new installed capacity at 34,669 kWp/month, and a noticeable smaller deviation at 1,743 kWp/month of investment under the quarter feedback and monthly adjustment mechanism compared to these values under the annual feedback mechanism (Fig 6).

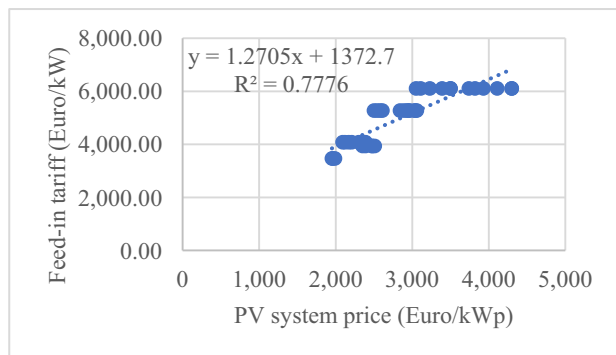


**Fig 7.** FIT, PV system price, NPV of small-scale solar power projects in Germany between Jan 2009 and Dec 2017

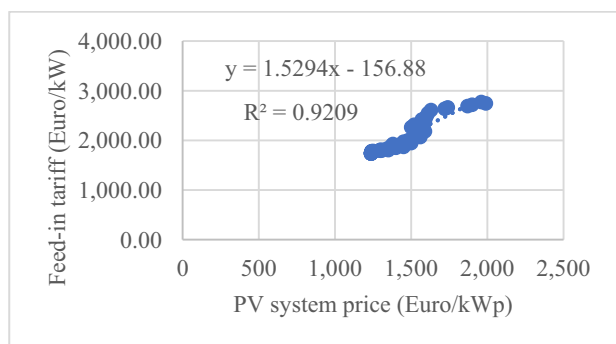
Between 2009 and 2012 the PV system price decreased continuously during the year (from around

2,950 Euro/kWp in January 2009 to 2,500 Euro/kW in December 2009, for example) while the FIT was fixed (at 5,279 Euro/kW during 2010). As a result, investors got more profit with the projects operated in the last months of the years. Since April 2014, we saw an adjustment of FIT in line with PV system price, and NPV was kept quite stable (Fig 7).

Using linear regression models, we see a better correlation between PV system price and FIT under the quarter feedback mechanism than the one of the annual responsive system.



**Fig 8.** Correlation between PV system price and FIT in Germany between Jan 2009 and Mar 2012



**Fig 9.** Correlation between PV system price and FIT in Germany between Apr 2012 and Dec 2017

For the period January 2009 – March 2012:

$$\widehat{FIT}_m = 1.271I_m + 1,372; R^2 = 77.76\% \text{ (Fig 8)}$$

For the period April 2012 – December 2017:

$$\widehat{FIT}_m = 1.529I_m - 156.88; R^2 = 92.09\% \text{ (Fig 9)}$$

A decrease of 1 Euro/kWp in PV system price caused a decline of 1.271 Euro/kW in FIT between January 2009 and March 2012, and 1.529 Euro/kW between April 2012 and December 2017. Moreover, under the annual feedback system, 77.76% change in FIT is explained by the change in PV system price while the number was 92.09% under a quarter feedback mechanism. In conclusion, a more frequent adjustment leads to a better control of FIT which reflects the cost of production.

#### 4 Conclusion, implication, and suggestions for further works

We admit that the price adjustment mechanisms have played a crucial role in controlling the renewable energy

investment and at the same time minimizing policy cost. Our findings include (1) the overinvestment in solar power led to the burden on electricity consumers because they had to pay higher EEG surcharge. The investors benefited from this event, however, the electricity users lost money. (2) The profit was the main impulse of investment decision. Net present value explained 65.23% the change in investors' decision. (3) Under the pre-regulated during the beginning years of the take-off phase, profitability demonstrated only 48.31% of investors' behavior. (4) The more frequent feedback system led to a better control of feed-in tariff. In other words, the feed-in tariff adjustment reflected better the trend of the electricity generation cost. (5) However, because there were no detailed mathematical shapes of feedback mechanisms, the quarter feedback control system was still not effective to control the volume of investment.

In this research, we have applied the linear regression models which are based on open-loop systems. However, for a mature solar power investment market like in Germany, technology costs have decreased slowly, the investment volume has been stable, an open-loop mechanism has shown some limitation that can be addressed by closed-loop systems or feedback control systems. Furthermore, the underinvestment in recent years reveals that apart from profit, existing other factors affecting investment decision such as a lower profit than investors' expectation or a rooftop, land limitation for solar power projects, etc. Therefore, further works are to design detailed mathematical shapes of feedback mechanisms which take into account other factors apart from profitability

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