Energy Policy 81 (2015) 86–97

Contents lists available at ScienceDirect

Energy Policy

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

Revenue prospects of photovoltaic in Germany—Influence opportunities by variation of the plant orientation

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HIGHLIGHTS

- Simulated PV generation profiles are combined with actual electricity market data.
- The (energy yield)-elasticity is a useful measure for an energy economic comparison.
- The energy yield-maximizing PV orientation is currently still the economic optimum.
- The merit order effect of PV generation will change future market conditions for PV.
- The remuneration scheme has to consider the grid situation and the PV potential.

ARTICLE INFO

Article history:
Received 24 August 2014
Received in revised form
16 February 2015
Accepted 20 February 2015
Available online 3 March 2015

Keywords:
Photovoltaic
Market integration
Premium schemes
German energy transition

ABSTRACT

The fixed feed-in tariff under the Renewable Energy Sources Act in Germany particularly encourages photovoltaic systems with the highest possible annual yield, regardless of their temporal generation profile. Consequently, a large part of the installed photovoltaic systems in Germany have a southern orientation. This paper examines how the optional German market premium scheme incentivizes the installation of photovoltaic systems with a more demand-oriented electricity production. For this purpose, the measure 'energy yield elasticity (of market value)' was developed and calculated by using historical market data. The results show that some of the plant orientations that are deviating from the southern reference could have led to an increase in the market value in the last few years. However, these would not have been high enough to more than compensate for the financial losses that were formed as a result of the annual energy yield declines. The merit order effect could change this situation in the future.

1. Introduction

The compensation rules in the Renewable Energy Sources Act (Erneuerbare Energien Gesetz, EEG) for photovoltaic (PV) systems allow three basic possibilities for the profit maximization strategy of potential investors and plant operators: maximizing the amount of energy produced annually, maximizing the (partial) private consumption as well as maximizing the (relative) market value of the PV generation. Ideally, these can be combined with each other. In this context, the valuation of electricity has become a frequently discussed subject. There are various valuation concepts available for variable renewable energies, whereby not all of them are coupled with time-dependent market prices though.

In Germany, the maximization of the amount of energy produced annually is incited by the fundamental principle of the EEG, being a fixed feed-in tariff. The exact time of electricity production is irrelevant for the amount of remuneration per unit of energy. Nevertheless, in an electricity system with a high share of variable renewable energy, an additional need for balancing is generated. This can be satisfied by flexible generation, storage systems, electricity imports, heat applications, electro mobility, grid improvement or demand side management. Another option is a more demand-oriented feed-in by variable renewable generators themselves, which is, aside from unchangeable meteorological conditions, possible to a certain degree. In order to incentivize this generation profile, the financing flows for a 'maximizing the value'-operation by either the renewable remuneration scheme or by the wholesale market has to be greater than for a 'maximizing the energy quantity'-operation (Häseler, 2014). For this purpose, the market premium model was introduced as a voluntary alternative

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http://dx.doi.org/10.1016/j.enpol.2015.02.017
0301-4215/

to the fixed feed-in tariff as part of an amendment of the EEG in 2012. In the most recent amendment of the EEG in August 2014 (EEG, 2014), only renewable electricity-generating facilities with a maximum power output less than a predetermined value are able to choose the fixed feed-in tariff. The market premium model is therefore mandatory for any other renewable generators. In this respect, exposing renewables to price risks and providing renewable energy operators with incentives for adapting their production to market conditions is called 'market integration' (Gawel and Purkus, 2013).

In contrast to the feed-in tariff, the renewable electricity must be sold on the wholesale power markets or directly to consumers under the market premium scheme. The proceedings consist of the earnings obtained by the market or private sales and the so called 'market premium'. This premium can vary monthly and is equal to the difference between the technology-specific feed-in tariff and the technology-specific average market sales (called 'market value'). When using the optional market premium, a change in the production profile can be financially profitable for the owner of a PV power plant compared to maintaining the plant at an orientation that produces the maximum annual energy yield. An increase in revenues may be possible by increasing the relative market value of the PV system in comparison to the national average (see Sensfuß and Ragwitz, 2011; Klobasa et al., 2013).

The (partial) private consumption is another option for maximizing the value of the electricity produced by a PV plant. This is a more complex function which mainly depends on the demand profile, the costs for shifting the demand and the (time-varying) electricity procurement costs. These are all individual factors however. As the focus of this paper lies on the incentives for adapting the PV production to wholesale market conditions, private consumption is not taken into consideration any further.

The generation profile of a PV system installed in Germany can, apart from the usage of an energy storage system, primarily be affected by the following factors:

- Geographic location within Germany.
- Angle of attack of the module (0° horizontally to 90° vertically).
- Azimuth angle of the module (90° west to −90° east).

The aim of this work is to examine to what extent the variation of the above mentioned factors can be used to increase remuneration within the EEG. For this purpose, consistent investment and operating costs for all PV module variations are assumed.[1] A PV simulation model was used for generating electricity production profiles of different locations and module orientations. Similar to the case-study of Rowlands et al. (2011) for Ontario (Canada), the generation profiles were combined with actual electricity market data. By doing so, the orientation with the highest proceedings under the market premium scheme could be compared to the energy yield-maximizing orientation. Furthermore, this comparison was systemized by developing the indicator '(energy yield)-elasticity of the plant'.

The article is divided into five parts. Following this introduction, the PV model that is used is shortly described in Section 2. Within this section the economic comparison under the market premium scheme is systemized by using an indicator which is relatively easy to calculate and applicable to different market-based remuneration schemes. The results of the model calculations are divided into three steps and can be found in Section 3. In the first step, the influence by different locations and orientations of a PV plant in Germany on the production volume and the production profile is analyzed. In the second step, the influence of different production profiles on the market values are calculated with historical market price data. Lastly, in the final step, the economic incentives for investing in PV systems with a demand-oriented orientation are analyzed by calculating the (energy yield)-elasticity of the PV power plant. In Section 4, these results are compared with other studies and are discussed in the context of the merit order effect of PV electricity production. Finally, in Section 5, consequences for the policy instruments, which are needed to attain a system-optimal integration of PV power plants, are discussed.

2. Methods

2.1. PV model

The model of Lukits (2013), which is described below, is applied to calculate the solar radiation and the resulting PV generation profiles. These are used for the analysis of the effects of a change in the azimuth angle, the angle of attack as well as the location of a PV system.

The model calculations are based on the measurement data of 114 weather stations of the German Meteorological Service (Deutscher Wetterdienst, DWD) from the MIRAKEL database from which the Federal Office for Building and Regional Planning (Bundesamt für Bauwesen und Raumordnung) has then again defined 15 representative stations. Each of the stations represents a TRY-climatic region (Test Reference Year), for which a record has been created respectively, reflecting the characteristic climate conditions of the region. These are based on time series with hourly averages for the years 1988–2007 and cover the measurement parameters of direct radiation, diffuse solar radiation, degree of cloud coverage and temperature.[2]

For the calculation of solar radiation on a plane or on a PV module, the distinction between a direct and a diffuse radiation portion, which together form the so-called global radiation, is necessary. The proportion of the two radiation components thereby has a significant impact on the energetic use of solar radiation by PV power plants. While the calculation of the direct radiation takes place on an inclined plane on the basis of the geometric relationship between the zenith angle and angle of incidence, the anisotropic Hay–Davies–Klucher–Reindl model is chosen for the determination of the diffuse radiation portion (see Maatallah et al., 2011). An overview of the main technical specifications of the used PV model is given in Table 1. For a detailed description of the model and the calculation of the global radiation used see Lukits (2013, pp. 24 ff).

After the calculation of the global radiation, the determination of the performance of a PV reference system was carried out at one of the defined locations following Chow and Chan (2004). This takes various factors such as glass reflection losses, losses due to partial shading, contamination etc. as well as the influence of the cell temperature on the module performance into account.[3] As a reference system, the polycrystalline module, Sunmodule Plus SW 255 poly' produced by the company Solarworld was used.

In summary, the model achieves the following key calculations:

- Hourly global radiation on a surface in the reference year, where the azimuth angle can be varied to direct to the east, west and south, the angle of attack can be varied between 0°

[1] Due to this assumption, an increase of the proceeds is equivalent to an increase in profits.

[2] The measurements also contain other meteorological data, such as the wind speed, which are not needed for the calculation of PV production profiles though.

[3] See Chang (2009) for the exact calculation of the cell temperature.