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Mark Andor, Manuel Frondel, and Colin Vance[1]

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Abstract

Using detailed data originating from several hundred households of the German Residential Energy Survey (GRECS), this paper empirically investigates the returns on investment in home-equipped photovoltaics (PV) installations. We find that these returns were particularly high in the years 2009 to 2011, when large subsidies for solar electricity coincided with plummeting module prices. While our empirical analysis demonstrates that such investments also incur substantial risks, there is evidence that, above all, wealthy households tend to benefit from the solar subsidies, whereas the costs of financing these subsidies are borne by electricity consumers at large, not least poverty-endangered households. The resulting redistribution of financial resources raises the question of whether the burden-sharing of Germany's transition to an alternative energy system is fair.

JEL Classification: Q28, Q42, Q48

Keywords: Solar subsidies, redistribution effects; German Residential Energy Consumption Survey

1 Mark Andor, RWI; Manuel Frondel, RWI and RUB; Colin Vance, RWI and Jacobs University. *– We gratefully acknowledge financial support from the German Ministery of Education and Research (BMBF) within the framework of the project "Akzeptanz", Research Grant: 01 UN 1203C. We are very grateful to Sophie Sendler for excellent research assistance. This paper is an updated and augmented version of the article by Andor, M. A., Frondel, M., Sendler, S. (2015) „Photovoltaik-Anlagen in Deutschland: Ausgestattet mit der Lizenz zum Gelddrucken?", which will be published in Zeitschrift für Energiewirtschaft.* *– All correspondence to: Manuel Frondel, RWI, Hohenzollernstr. 1-3, 45128 Essen, Germany, e-mail: manuel.frondel@rwi-essen.de.*

1 Introduction

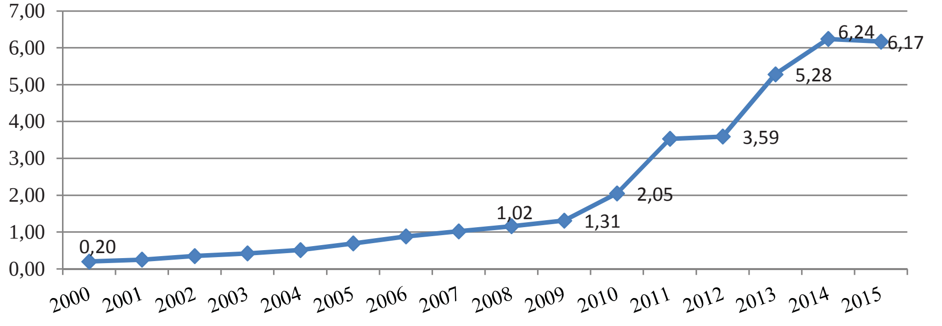
Germany’s transition to an alternative energy system is mainly characterized by the promotion of renewable energy technologies and the phase-out of nuclear power by the end of 2022. This transition will inevitably lead to further increasing electricity prices (Frondel, Sommer, Vance, 2015) and bodes poorly for many low-income households. Power prices for German households have already doubled since the introduction of the feed-in-tariff (FIT) promotion scheme for renewable energy sources (RES) in 2000.

This promotion scheme, which is legally codified under the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG), has established itself as a global role model. FITs have been adopted by a wide range of countries throughout the world, even by countries with a high endowment of sun such as Australia (Nelson, Simshauser, Kelley, 2011; Nelson, Simshauser, Nelson, 2012). Among the countries of the European Union, FITs have become the most popular promotion scheme for RES (CEER, 2013).

Under the EEG legislation, utilities are obliged to pay technology-specific feed-in tariffs far above own production costs to those who produce green electricity using alternative technologies, such as solar and wind power plants. Ultimately, though, it is the industrial and private consumers who have to bear the costs induced by the promotion of renewable energy technologies through a surcharge on the price of electricity (Frondel et al., 2010). Between 2009 and 2015, this surcharge almost quintupled, rising from 1.31 euro cents per kilowatt-hour (kWh) to 6.17 ct/kWh (Figure 1).

A key reason for this strong increase was the massive installation of photovoltaic (PV) capacities in recent years: At the end of 2014, total PV capacities exceeded 38 Gigawatt (GW), an amount that was more than six times higher than the 6 GW that had been installed until 2008 (BMWi, 2014a, Table 1). This is a consequence of the so-called solar boom in Germany, which primarily occurred in the years 2010 to 2012 (Table 1), when the newly installed capacities exceeded 7 GW each year.

Figure 1: EEG Surcharge on Electricity Prices for the Promotion of Renewable Technologies in Cents per kWh



Source: BDEW (2014)

Table 1: Conventional and RES Capacities in Germany

Year	Hydropower (MW)	Onshore-Wind (MW)	Offshore-Wind (MW)	Photovoltaik (MW)	Biomass (MW)	RES Capacities (MW)	Conventional Capacities (MW)
2000	4,831	6,097	0	114	1,288	12,330	107,500
2001	4,831	8,738	0	176	1,412	15,157	106,800
2002	4,937	11,976	0	296	1,615	18,824	100,900
2003	4,953	14,593	0	435	2,329	22,311	99,400
2004	5,186	16,612	0	1,105	2,630	25,533	100,900
2005	5,210	18,375	0	2,056	3,526	29,167	98,800
2006	5,193	20,568	0	2,899	4,283	32,943	98,400
2007	5,137	22,183	0	4,170	4,723	36,216	99,800
2008	5,164	23,815	0	6,120	5,256	40,358	101,700
2009	5,340	25,632	60	10,566	5,995	47,601	101,300
2010	5,407	27,012	168	17,554	6,599	56,748	104,000
2011	5,625	28,857	203	25,039	7,148	66,880	98,000
2012	5,607	30,996	308	32,643	7,537	77,103	97,300
2013	5,613	33,757	903	35,948	8,086	84,338	94,000

Source: BMWi (2014a, b). With an installed capacity of 24 MW in 2013, geothermic systems are of negligible relevance and thus not included in the table.

As a result, according to calculations by Frondel, Ritter, Schmidt (2008), Frondel et al. (2010) and Frondel, Schmidt, Vance (2014), the real net costs for all those modules installed between 2000 and 2014 amounts to almost 112 Bn euros (Table 2), while PV currently contributes just about 5% to total electricity production. Triggered by these tremendous costs, there is a controversial debate on the benefits and consequences of Germany's solar boom. HEINDL, SCHÜßLER and LÖSCHEL (2014: 509), for instance, argue that there are strong redistribution effects, as it is primarily homeowners who may benefit from the solar subsidies, while all the electricity consumers from the residential, industrial and other sectors have to bear the large burden of these subsidies (FRONDEL, SOMMER 2014). According to estimations by BARDT and NIEHUES (2013: 213ff.) on the basis of data from the German Socioecononmic Panel (GSOEP), about one million of the 42 million German households have installed PV modules so far, with which they realize annual surpluses of about one billion euros. More than half of these surpluses are garnered by households originating from the top three deciles of the income distribution (BARDT, NIEHUES, 2013: 217). Moreover, it is suspected that this redistribution from rather poor to more wealthy households that own PV modules goes along with returns that are much larger than those of comparable investments.

Table 2: Capacities and Net Costs of Germany's Photovoltaics Promotion

	Annual Capacity Increases and resulting Solar Electricity Yields		Net Costs	
	MW	Mio. kWh	Bn. €	Bn. €$_{2012}$
2000	53	43	0.389	0.413
2001	110	89	0.802	0.836
2002	110	89	0.752	0.768
2003	139	112	0.889	0.890
2004	670	542	4.779	4.690
2005	951	769	7.338	7.057
2006	843	682	6.094	5.748
2007	1 271	1 028	8.595	7.951
2008	1 950	1 577	12.316	11.175
2009	3 794	3 068	19.810	17.642
2010	7 406	5 988	30.230	26.443
2011	7 485	6 054	20.628	17.761
2012	7 522	6 083	9.610	8.229
2013	3 304	2 671	1.902	1.649
2014	1 899	1 536	0.516	0.456
Total Net Costs 2000-2014:			**124.650**	**111.708**

Sources: Annual Capacity Increases: BMU (2011), BNETZA (2015). Net Cost: Own calculations based on Frondel, Ritter, Schmidt (2008), Frondel et al. (2010) und Frondel, Schmidt, Vance (2014).

To provide for an empirical basis for this speculation, this article estimates a bandwidth for the returns on investment in PV modules, employing detailed data originating from the German Residential Energy Survey (GRECS) for the years 2007-2013. Based on the annual solar electricity yields and the PV capacities installed by several hundred households, we find that these returns were particularly high in the years 2009 to 2011, when large subsidies for solar electricity coincided with plummeting module prices. We also present evidence showing that income and wealth are significant correlates of PV installations.

The following section describes the data basis and the basic assumptions underlying our calculations. Section 3 presents our estimates of the returns, followed by a sensitivity analysis set out in Section 4. Section 5 analyzes econometrically the household-level correlates of PV installations. The last section summarizes and concludes.

2 Data and Basic Assumptions

Our empirical analysis draws on the data of three waves of the German Residential Energy Survey (GRECS) for the years 2006-2008, 2009-2010, and 2011-2013. The number of households that participated in the surveys amounted to 6,714, 7,125 and 8,561, respectively (RWI, forsa, 2011, 2013, 2015). These surveys gathered energy-related information from participants, including the availability of PV installations and other alternative energy technologies at the households' residence.

In total, 563 households indicated that they own PV modules.[1] About one fourth of them are among the high-income households, disposing of a monthly net income of more than 4,200 euros, whereas 8.2% of these households state that their net income is lower than 1,700 euros. These figures support the assumption that PV modules are more common in high-income households. This assumption,

[1] The capacity distribution of these households' PV installations is presented in Table A1 in the appendix.

which we verify below with a probit model, is confirmed by the fact that 90 % of those households with PV installations are owners of their residence.

Of the 563 households with PV modules, only 294 provided all the information that is required for calculating returns on investment, most notably the year of PV installation, the capacity in kilowatts (kW), as well as the individual solar electricity yield in 2013.[2] Both the information on the year of installation and the capacity determine the individual feed-in tariff (FIT) in euros per kWh that a household receives for producing solar electricity and feeding it into the public grid. By multiplying the individual FIT with the annual solar electricity yield in 2013, the annual revenues from PV installations can be calculated.

To estimate the revenues not just for 2013, but for all those years since a household installed PV modules at home, we estimate the unknown solar electricity yields for the year *t* prior to 2013 by modulating the yields of 2013 on the basis of data on state-specific sunshine hours. In detail, the unknown solar electricity yield for the year *t* is calculated using the following equation:

Solar electricity yield in t = Electricity yield in 2013 * # Sunshine hours in t /# Sunshine hours in 2013, (1)

where the number (#) of annual sunshine hours for each of the 16 German federal states is provided by Deutscher Wetterdienst (DWD, 2015). This calculation is based on the assumption that the number of sunshine hours is the dominant determinant of a PV module's solar electricity yield, an assumption that appears to be warranted, as other factors, such as maintenance periods, are of minor importance (BARDT, NIEHUES 2013: 216).

Estimating the annual profits requires subtracting maintenance costs, annual depreciation, and other costs from total revenues. To this end, for the base model we assume a linear depreciation rate over the period of 20 years during which it is legally ensured that households receive subsidies in the form of solar FITs. Annual maintenance costs are assumed to account for 1% of total installation costs (ACKER, 2015a; FINKE, 2015a; MADEL, 2015). Not included in the base

[2] The mean solar electricity yield of these 294 households amounted to about 830 kWh per kW in 2013.

model are insurance costs and the opportunity to finance the investment by loans, both of which are taken into account in our sensitivity analysis. Instead, the base model assumes that households had financed their PV investments entirely with their own money when calculating the return estimates presented in the following section.

As we have no information on the individual acquisition costs, we have estimated each household's investment amount on the basis a price index for ready-to-use PV installations (ZIEGLER, 2015). In our sensitivity analysis, we have varied this price information to account for the possibility that households may have paid substantially different prices than indicated by this price index.

In determining the individual return on investment, it bears noting that the invested capital is not bound over the entire service life of the PV installation. This is because in each year operating revenues are generated that can be reinvested. We therefore invoke the simplifying assumption that, on average, the bound capital amounts to half of the acquisition costs over the life service of the module (see WÖHE, DÖRING 2008: 529). Accordingly, our calculation of the returns divides the yearly profits by half of the one-time acquisition costs, *I*:

$$r_t = \frac{\theta * q_t - A_t - c_t}{\frac{I}{2}}, \qquad (2)$$

where q_t denotes the solar electricity fed into the grid in year *t*, θ is the guaranteed feed-in tariff, A_t the annual depreciation, and c_t are the annual operating costs.

3 Return on Investment Estimates

As is evident from Table 3, a strong determinant of the return on investment is the year of installation: With average returns of more than 10%, the highest rents can be found for PV modules that were installed in the years 2009, 2010, and 2011. In contrast, the average return on investment is lowest for those modules that were installed in 2012. Across all PV installations of 2012, the mean return amounts to 4.5% for 2013 (Table 3).

Similarly large discrepancies across the years of installation can be observed for the annual surpluses: with an average of 306 euros per year and installation, the surpluses are lowest for those modules that were installed in 2012. In contrast, the highest mean surplus of 1,210 euros per annum results for the installation year 2010. This outcome is virtually identical to the surplus estimated by BARDT and NIEHUES (2013: 217) for the same year on the basis of theoretical assumptions, rather than empirical evidence. These authors reckon that for modules with a capacity of 10 kW that were installed in 2010, the monthly surplus amounts to 100 euros.

Table 3: Average Returns on Investment in PV Installations of German Households in the years 2008 to 2013

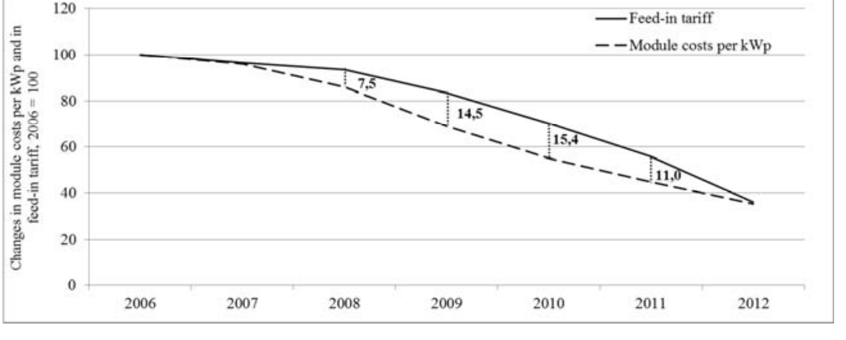
	Year of installation						Average sunshine (Hours/Year)
	2007	2008	2009	2010	2011	2012	
2008	7.18%						1,623
2009	7.39%	10.18%					1,678
2010	5.90%	9.47%	9.91%				1,533
2011	9.84%	10.31%	14.54%	15.36%			1,839
2012	7.93%	8.32%	12.07%	12.89%	13.38%		1,662
2013	5.50%	6.47%	9.21%	9.93%	10.46%	4.50%	1,488
Mean	7.29%	8.95%	11.43%	12.73%	11.92%	4.50%	
# of obs.	15	20	44	91	60	64	
Federal bond rate	4.51%	4.62%	4.33%	3.60%	3.51%	2.49%	
EURIBOR	4.45%	4.81%	1.62%	1.35%	2.01%	1.11%	

Naturally, the return on investment varies with the sunshine hours per year. Per assumption, this is the sole factor that explains the differences in the return estimates presented in Table 3. In fact, the unknown solar electricity yields for any year t other than 2013 are calculated on the basis of Equation 1, in which the ratio of sunshine hours of year t and 2013 is an essential ingredient. From Table 3 emerges that, in addition to the year of installation, the low number of sunshine hours in 2013 is an important factor in explaining the relatively low returns on investment in that year. On the other hand, irrespective of the year of installation, the highest returns result for 2011, the year with the highest number of sunshine hours within the period 2008 to 2013.

To compare the returns on investment in PV installations with the returns of alternative investments, two distinct interest rates are reported in Table 3: that of the EURIBOR (Euro Interbank Offered Rate) with a maturity period of 12 months (DEUTSCHE BUNDESBANK 2015a, b) and the interest rate of a German government bond with a maturity period of 20 years, which corresponds to the period during which FIT payments for solar electricity generation are guaranteed. Table 3 reports the annual means of the monthly published interest rates of both these investment alternatives.

It turns out that for 2008 the average return of 7.18% on PV modules that were installed in 2007 is substantially larger than the interest rates reported in Table 2 for the same year. This spread grew notably in the aftermath of the global finance and debt crisis that emerged at the end of the last decade. The strong increase in the relative profitability of PV installations after 2008 also becomes apparent from the comparison of the evolution of installation costs and FITs (Figure 2). Most notably, average installation costs shrank much more in the years 2009 to 2011 than the FIT level, leading to particularly large returns for those modules that were installed in these years (BARDT, NIEHUES 2013: 216).

Figure 2: Evolution of Installation Costs and Feed-in Tariffs for Photovoltaics



Source: BDEW (2014), ZIEGLER (2015).

4 Sensitivity Analysis

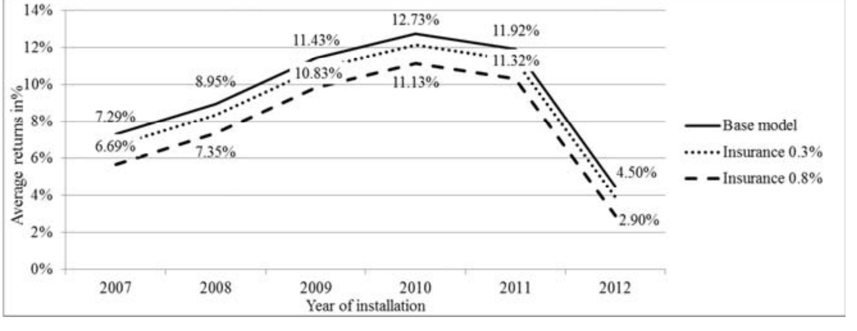
We now investigate the robustness of our return estimates presented in the previous section. To this end, we alter several of the assumptions set out in Section 2.

For example, in addition to maintenance costs, we now also subtract insurance costs from the annual revenues.

Insurance Costs

Given potential damage due to storms, fire and hail, corresponding risk insurance is available. In addition to the compensation of module damages, such insurance typically also compensates for forgone FIT revenues (MEYER, 2015). Commonly, the annual premium for such insurance amounts to about 0.3-0.8% of total acquisition costs (FINKE, 2015b). Along with operating costs and depreciation, the yearly insurance premium is subtracted from the FIT revenues when calculating the returns presented in Figure 3. While the resulting decreases in returns highlight the appreciable impact of insurance on the investment decision, the average returns on PV units installed between 2009 and 2011 nevertheless remain in the double-digit percentage point range.

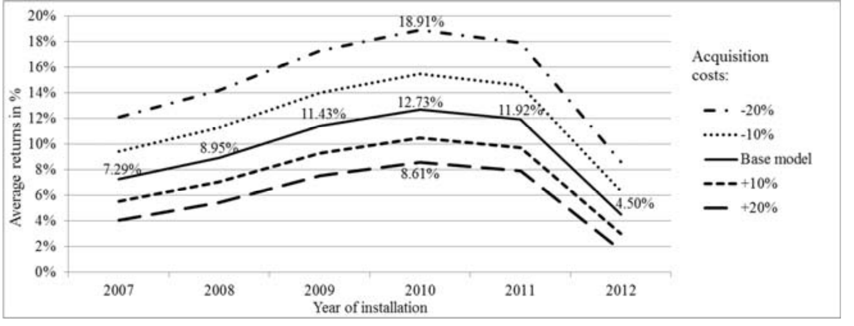
Figure 3: Returns to PV Installations given different Insurance Premia



Acquisition Costs

As the survey did not include information on individual acquisition costs, these were estimated with the aid of a price index for ready-to-use installations. Recognizing that the actual investment costs are likely to deviate from this reference line, we allow for variation in the acquisition costs ranging between -20% to +20%. The corresponding range in the estimated returns for modules installed in 2010, the year with the most favorable ratio of costs to the FIT according to Figure 1, varies between 8.61% and 18.91% (Figure 4). This bandwidth highlights the importance of the acquisition costs for the obtainable return.

Figure 4: Effects of Variation in the Acquisition Costs on the Returns to PV Installations



Replacement of the Converter

Every PV system requires a so-called inverter to convert the generated electricity into the commonly used alternating current (AC). Converters typically have a service life of about 10 years, depending on their quality (ACKER, 2015b). We can consequently assume that an inverter would need to be replaced on average one time during the 20 year period covered by the FIT. The cost of a new converter amounts to approximately 10% of the acquisition costs (ACKER, 2015b, ZAHN, 2015). The effect of these additional costs can therefore be seen from the curve in Figure 4 showing the returns corresponding to 10% higher acquisition costs than is assumed in the base model.

Service Life of PV Installations

In the absence of comprehensive historical values, it is typically assumed that PV installations have a service life of at least 20 years. PV manufacturers correspondingly offer guarantees that span over 25 years (ACKER, 2015c). Some sources cite service lives that even stretch to 30 or 40 years (ELSNER, 2012). This would increase the attainable returns beyond that suggested in the previous section by allowing for the own-use of solar electricity following the expiration of support from the EEG. The possibility of a shortened service life, however, should also be considered. To compare these alternatives, Figure 5 presents the returns from the base model, which assumes a service life of 20 years, as well as the returns from alternative durations of 15, 25, and 30 years.

Figure 5: Effects of different PV Service Lives on Returns

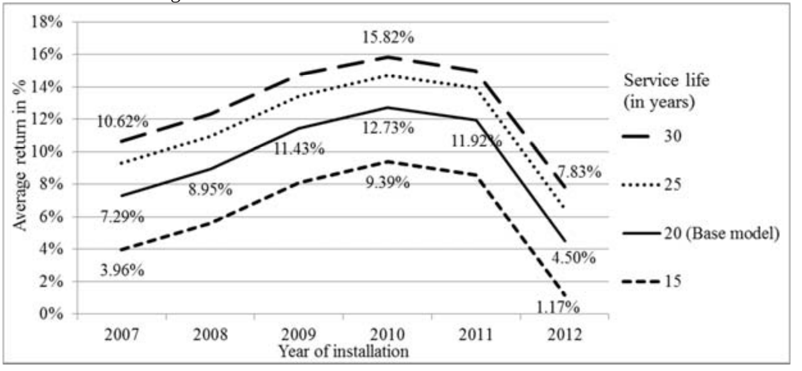


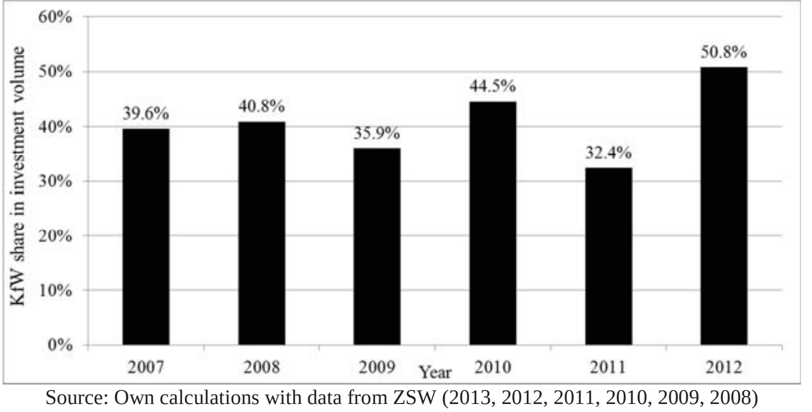
Figure 5 shows that reducing the service life from 20 to 15 years strongly reduces the returns. In the case of a PV module that was installed in 2012, this shortened 15 year service life would reduce the already relatively low returns from that year to 1.17%. On the other hand, a longer service life improves returns substantially: given a service life of 30 years, even units that were installed in 2012 achieve a return of 7.83%.

Debt Financing

The base model assumes that households finance 100% of the acquisition costs with their own funds. A majority of PV installations, however, are financed with borrowed capital, as occurs when seed money is not available or when attractive terms on borrowing are offered that increase returns. In past years, one such source for favorable credit was the KfW (Kreditanstalt für Wiederaufbau), which financed a large share of PV investments (Figure 6). By 2012, the share of KfW-financed PV installations in Germany had climbed rapidly to reach 50.7%.

The important role of the KfW in this context suggests further exploration of the so-called “Credit 274” program, through which the KfW specifically targeted PV installations. This should serve as a good reference point for investments of this kind. Because only the currently prevailing effective interest rate is posted on the KfW internet site, we undertake the following sensitivity analysis by estimating rates for 2007 to 2012 by assuming a constant differential between the KfW rate and the EURIBOR. This differential is calculated using the EURIBOR and the KfW effective interest rate for May 2015 as the reference point.

Figure 6: KfW Share of Investments in PV Installations in Germany



Source: Own calculations with data from ZSW (2013, 2012, 2011, 2010, 2009, 2008)

Investments in PV installations are typically not financed entirely through loans. According to figures from the KfW, the debt-financed share varies by 80% (see also ISE, 2013: 11). This is confirmed by the figures in Table 4, which shows the debt-share of financing to vary between 70 and 80% for the years 2007 through 2012.

Table 4: Loan and Investment Volumes of the KfW for Photovoltaics (2007 – 2012)

Year	2007	2008	2009	2010	2011	2012
Loan volume (in Bn. Euro)	1.7	2.5	3.8	6.8	3.9	3.9
Investment volume (in Bn. Euro)	2.10	3.26	4.89	8.18	4.86	5.68
Loan Investment Ratio (in %)	81%	77%	78%	83%	80%	69%

Source: Own calculations with data from ZSW (2013, 2012, 2011, 2010, 2009, 2008)

Debt financing of an investment can result in a leverage effect for the return on equity, $r_{EK,}$ when the investment return r exceeds the interest rate on the debt, r_{FK} (WÖHE, DÖRING 2008: 661):

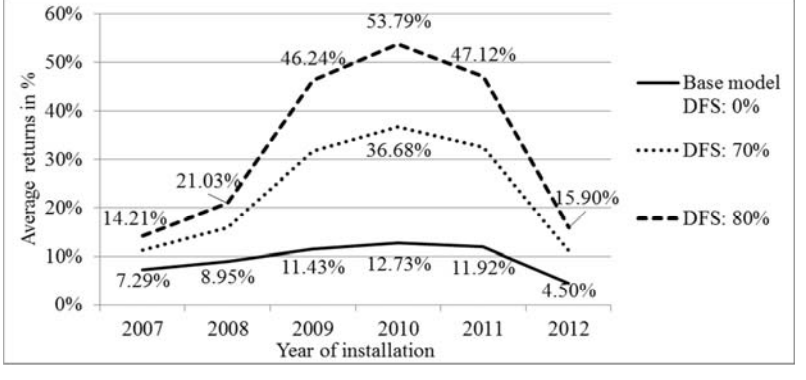
$$r_{EK} = r + V * (r - r_{FK}), \qquad (3)$$

where V is the debt to equity ratio: V = FK/EK. Favorable interest rates on debt accordingly improve the return on equity of an investment.

Whether interest rates are favorable depends heavily on the creditworthiness of a household, with higher rates corresponding to lower creditworthiness. This is seen from the rates of 1.35 %, 3.15 % and 7.75 % charged by KfW to households having a creditworthiness classification of good, average, and poor, respectively. Due to a lack of credit history information of households, we maintain this three-tiered classification in the comparison that follows.

The results presented in Figures 7, 8, and 9 indicate that for the installation years from 2009 to 2011, returns on equity of 30% and more could be achieved. Given a debt ratio of 80% and a good credit rating of the household, a 50% return on equity was even possible. As Figure 8 shows, households with an average creditworthy classification could also secure returns on equity well above those calculated in the base model.

Figure 7: Return on Equity given a good Credit Rating of the Borrowing Household (DFS: Debt-financed share)



Poor creditworthiness is likely to be rare among households investing in PV installations. Nevertheless, a closer look at this circumstance in Figure 8 reveals that such investments do carry risks, in some instances leading to negative returns on equity for households having a poor credit history.

Figure 8: Return on Equity given an Average Credit Rating of the Borrowing Household (DFS: Debt-financed share)

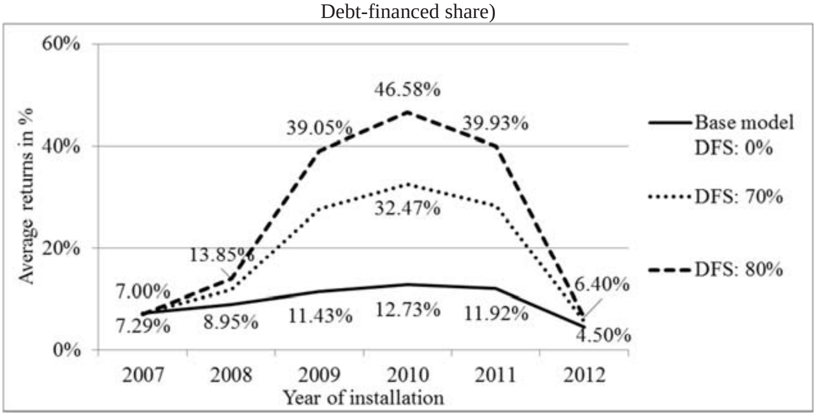
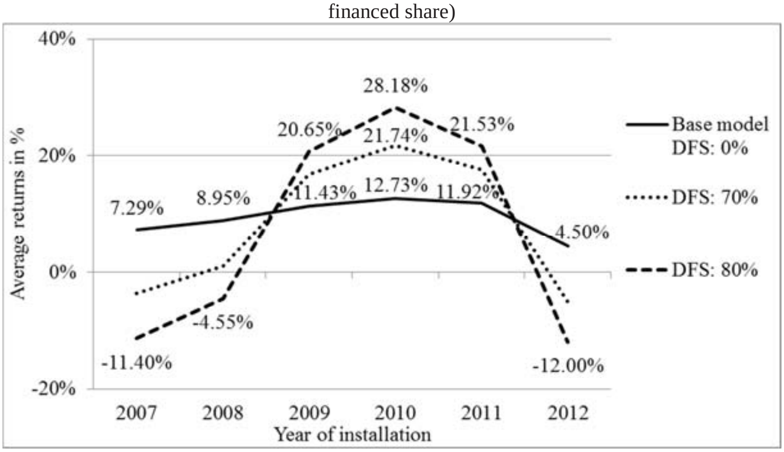


Figure 9: Return on Equity given a poor Credit Rating of the Borrowing Household (DFS: Debt-financed share)



Overall, these comparisons further confirm stark differences in returns according to the year the PV installation is brought into service. While the returns on equity were as high as 20% over the years from 2009 to 2011, they dipped into negative territory for poor creditworthy households and installations in the years 2007, 2008, and 2012.

5 Correlates of PV Installation

Having demonstrated the potentially high returns from an investment in PV installations underwritten by Germany's EEG, we now briefly turn to examine the characteristics of those households undertaking the investment. To this end, we estimate a probit model that relates the binary outcome of PV ownership to a suite of explanatory variables measuring household-level socio-economic attributes. These include dummy variables for various monthly income levels,[3] a continuous measure of the age of the household head, and dummies indicating different household size categories, whether the home is privately owned, whether it is a free-standing single- or two-family home, and its location in the country.

Table 5 presents the marginal effects estimated at the mean values of the explanatory variables, which reflect the change in probability corresponding to a unit change in the explanatory variables. Most of the estimates are statistically significant and all have plausible signs. Of particular interest from an equity perspective are the measures of income and wealth, both of which are seen to have positive associations with owing a PV installation. Specifically, those in the penultimate of the four income categories, who earn between 2,700 and 4,200 euros per month, have a probability of owning a PV installation that is 2.9 percentage points higher than those in the lowest income category, earning below 1,200 euros. A similar effect is seen for the highest income group, though it is not statistically significant. Even stronger effects are seen for the wealth indicators. Those owing their home have a 5.6 percentage points higher probability of owning a PV installation than non-owners, while the corresponding figure for owners of a free-standing single or double house is 5.1 percentage points.

Not surprisingly, the probability of PV ownership is highest in the south of Germany, roughly 10 percentage points higher than in the north, where the sun intensity is lower. Demographic factors also matter: each year of increase in the age of the household head lowers the probability by 0.1 percentage points, while larger household sizes increase the probability. A household having a size of 5 or

[3] Our income measure is the sum of the household's total wage- and investment income, subtracting off the revenues generated from solar electricity.

more persons, for example, has a probability of owning a PV installation that is 7 percentage points higher than a single-person household.

Table 5: Probit model for Estimating the Probability of Owning a PV installation.

	Marginal Effects	Robust Standard Errors
1,200<=income <2,700	0.011	0.014
2,700<=income<4,200	0.029*	0.014
4,200<=income	0.025	0.016
Age of household head	-0.001**	0.000
2 person household	0.022	0.016
3 person household	0.053*	0.021
4 person household	0.044*	0.022
5 or more person household	0.070*	0.029
Own home	0.056**	0.009
1 or 2 family home	0.051**	0.008
South	0.096**	0.016
West	0.034*	0.013
East	-0.013	0.015
Number of Observations: 5,418		

Note: ** and * denote statistical significance at the 1% and 5 % level, respectively.

6 Summary

Evidence on the profitability of investments in PV-generated solar electricity has, with few exceptions (e.g. BARDT und NIEHUES 2013), been primarily anecdotal. The German Residential Energy Survey (GRECS), which RWI and forsa have implemented for over a decade under the commission of the Federal Ministry for Economic Affairs and Energy, contributes to filling this void in Germany, a country pursuing perhaps the most ambitious promotion of renewable energy globally. The survey regularly gathers detailed energy-related information from about 6,000 to 8,000 households, among which are several hundred households owning a PV installation. For these households, data on the start-up year of the PV installation, its capacity, and its yearly solar electricity yield is available, thereby allowing for an estimation of its profitability.

Our empirical analysis of the returns on investments in PV installations for the years 2008-2013 has demonstrated that the installation years from 2009 to 2011 were particularly lucrative. This outcome can be attributed to the confluence of high feed-in tariffs for solar electricity along with plummeting costs for the installations. We have also provided empirical evidence that those investing in PV installations tend to be wealthy households who have the requisite roof and open space available. Effectively, the high returns that these households enjoy on their investment are borne by the remaining electricity consumers, not least households threatened by energy poverty, who finance the substantial costs of PV promotion through higher electricity bills. Thus, aside from the highly dubious cost-effectiveness of Germany's Renewable Energy Law (Frondel et al., 2010), a fundamental question regarding its distributive impacts arises (Frondel, Sommer, Vance, 2015).

This question assumes increasing urgency with the growing role of solar electricity for own-use in driving the expansion of PV installations in Germany. Operators of smaller installations having a capacity of up to 10 kilowatts (kW), as is usually the case for private households, are not required under the current legislation to pay electricity taxes, levies, and other charges, such as network charges and the levy for promoting renewable power technologies, for electricity they generate and use themselves, implying increases in the electricity bills of the remaining residential electricity consumers. This discordance between those generating the solar electricity and those bearing the costs of this generation could lead to a self-reinforcing cycle: As levies and the network charges continue to grow due to the increasing own-use of solar electricity, so too will the incentives to produce more electricity for own-use (Bardt et al., 2014:94).

Further rising electricity prices coupled with lower prices for PV and complementary technologies, such as batteries for electricity storage, will only accelerate this process, especially as households realize opportunities for eventually becoming electricity-autarkic by exploiting storage capacities. Such a development would not only have negative distributional implications. It would also be questionable for efficiency reasons, not least because alternative technologies that do not lend themselves to own-use, such as wind power, would be disadvantaged.

Relative to a cost-minimizing outcome by the year 2025, Jägemann, Hagspiel and Lindenberger (2013:1) estimate the costs of the inefficiencies from households that equip themselves with PV- and storage technologies to be 116 billion euros (in prices of 2011). The extent of these inefficiencies could be much stronger if companies from industry and from the trade, commerce and services sector take advantage of these opportunities. Solarboom 2.0 may thus become reality, with the attendant costs, inefficiencies, and inequities brought by the first boom.

APPENDIX

Table A1: Size distribution of PV installations in the survey

Module size in kWp	# households	Share
up to 5	117	34.1%
up to 10	150	43.7%
up to 15	50	14.6%
up to 20	10	2.9%
up to 30	8	2.3%
up to 40	8	2.3%
Total	343	100.0%

Source: Own calculations

References

Acker, Ursula (2015a) Photovoltaik Kosten, online: http://www.photovoltaik.org/betrieb/photovoltaik-kosten.

Acker, Ursula (2015b) Wechselrichter, online: http://www.photovoltaik.org/ratgeber/wechselrichter.

Acker, Ursula (2015c) Lebensdauer einer Photovoltaikanlage, online: http://www.photovoltaik.org/wissen/lebensdauer-einer-photovoltaikanlage.

Bardt, Hubertus, Niehues, Judith (2013) Verteilungswirkungen des EEG, Zeitschrift für Energiewirtschaft 37(3), 211-218.

Bardt, Hubertus, Chrischilles, Esther, Growitsch, Christian, Hagspiel, Simeon, Schaupp, Lisa (2014) Eigenerzeugung und Selbstverbrauch von Strom – Stand, Potentiale, Trends, Zeitschrift für Energiewirtschaft 38(2), 83-99.

BMWi (Bundesministerium für Wirtschaft und Energie) (2014a) Erneuerbare Energien im Jahr 2013. Erste vorläufige Daten zur Entwicklung der erneuerbaren Energien in Deutschland auf der Grundlage der Angaben der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat). Berlin.

BMWi (Bundesministerium für Wirtschaft und Energie) (2014b) Zahlen und Fakten. Energiedaten, Nationale und interanationale Entwicklung. Berlin. online: http://www.bmwi.de/DE/Themen/Energie/Energiedaten-und-analysen/Energiedaten/gesamtausgabe,did=476134.html.

CEER (Council of European Energy Regulators) (2013) Status Review of Renewable and Energy Efficiency Support Schemes in Europe. Brussels.

Bundesnetzagentur (BNetzA) (2015) Photovoltaikanlagen Datenmeldungen sowie EEG-Vergütungssätze, Bonn, online: http://www.bundesnetzagentur.de/

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2011) Erneuerbare Energien 2010. Daten des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit zur Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2010 auf der Grundlage der Angaben der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat). Vorläufige Angaben, Stand 23. März 2011, Berlin.

Bundesverband der Energie - und Wasserwirtschaft (BDEW) (2014) Erneuerbare Energien und das EEG: Zahlen, Fakten, Grafiken (2014), Energie-Info, online: https://www.bdew.de

DEUTSCHE BUNDESBANK (2015a) Renditen der Bundesanleihen, Zinsstrukturkurve (Svensson-Methode) / Börsennotierte Bundeswertpapiere / 20,0 Jahr(e) RLZ / Monatsendstand, online unter: http://www.bundesbank.de

DEUTSCHE BUNDESBANK (2015b) Geldmarktsätze nach Monaten, Geldmarktsätze / EURIBOR / Zwölfmonatsgeld / Monatsdurchschnitt, online: http://www.bundesbank.de

DEUTSCHER WETTERDIENST (DWD) (2015) Zeitreihen von Gebietsmittel - Sonnenscheindauer, online: http://www.dwd.de

ELSNER, ALOIS (2012) Planung PV-Anlagen, online: http://www.gutachten-pv.eu/pv-anlagenplanung/.

FINKE, STEFAN (2015a) Lohnt sich Photovoltaik weiterhin?, online: http://www.photovoltaiksolarstrom.de/lohnt-sich-photovoltaik.

FINKE, STEFAN (2015b) Photovoltaik-Kosten im Jahr 2015, online: http://www.photovoltaiksolarstrom.de/photovoltaik-kosten.

FRAUNHOFER-INSTITUT FÜR SOLARE ENERGIESYSTEME (ISE) (2013) Stromgestehungskosten erneuerbare Energien. Studie des ISE, Freiburg, November 2013, online: http://www.ise.fraunhofer.de/de/veroeffentlichungen/veroeffentlichungen-pdf-dateien/studien-und-konzeptpapiere/studie-stromgestehungskosten-erneuerbare-energien.pdf

FRONDEL, MANUEL, RITTER, NOLAN, SCHMIDT, CHRISTOPH M. (2008) Germany's Solar Cell Promotion: Dark Clouds on the Horizon. Energy Policy 36(4), 4198-4204.

FRONDEL, M., RITTER, NOLAN, SCHMIDT, CHRISTOPH M., VANCE, COLIN (2010) Economic Impacts from the Promotion of Renewable Energy Technologies: The German Experience. Energy Policy 38(8), 4048-4056.

FRONDEL, MANUEL, SCHMIDT, CHRISTOPH M., VANCE, COLIN (2014) Revisiting Germany's Solar Cell Promotion: An Unfolding Disaster. Economic Analysis and Policy 44(1), 3-13.

FRONDEL, MANUEL, SOMMER, STEPHAN (2014) Energiekostenbelastung privater Haushalte: Das EEG als sozialpolitische Zeitbombe?, List Forum für Wirtschafts- und Finanzpolitik 40(4), 382-402.

FRONDEL, MANUEL, SOMMER, STEPHAN, VANCE, COLIN (2015) The Burden of Germany's Energy Transition - An Empirical Analysis of Distributional Effects. Economic Analysis and Policy 45, 89–99.

HEINDL, PETER, SCHÜẞLER, RUDOLF, LÖSCHEL, ANDREAS (2014) Ist die Energiewende sozial gerecht?, Wirtschaftsdienst 94 (7), 508-514.

Jägemann, Cosima, Hagspiel, Simeon, Lindenberger, Dietmar (2013) The Economic Inefficiency of Grid Parity: The Case of German Photovoltaics. EWI Working Paper 13/19, Energiewirtschaftliches Institut der Universität zu Köln.

Madel, Andreas (2015) Photovoltaik Betriebskosten, online: http://www.solaranlage-ratgeber.de/photovoltaik/photovoltaik-wirtschaftlichkeit/photovoltaik-betriebskosten.

Meyer, olaf (2015) Photovoltaik Versicherung für PV-Anlagen vergleichen, online: https://www.photovoltaik-versicherung-vergleichen.de/.

Nelson, T., Simshauser, P., Kelley, S. (2011) Australian Residential Solar Feed-in-Tariffs: Industry Stimulus or Regressive Form of Taxation. Economic Analysis and Policy 41(2), 113-129.

Nelson, T., Simshauser, P., Nelson, J. (2012) Queensland Solar Feed-In-Tariffs and the Merit-Order Effect: Economic benefit, or Regressive Taxation and Wealth Transfers? Economic Analysis and Policy 42(3), 277-301.

Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), forsa Gesellschaft für Sozialforschung und statistische Analysen mbH (2015) Erhebung des Energieverbrauchs der privaten Haushalte für die Jahre 2011-2013, online: http://www.rwi-essen.de/haushaltsenergieverbrauch.

Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), forsa Gesellschaft für Sozialforschung und statistische Analysen mbH (2013) Erhebung des Energieverbrauchs der privaten Haushalte für die Jahre 2009-2010, online: http://www.rwi-essen.de/haushaltsenergieverbrauch.

Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), forsa Gesellschaft für Sozialforschung und statistische Analysen mbH (2011) Erhebung des Energieverbrauchs der privaten Haushalte für die Jahre 2006-2008, online: http://www.rwi-essen.de/haushaltsenergieverbrauch.

Wöhe, Günter, Döring, Ulrich (2008) Einführung in die Allgemeine Betriebswirtschaftslehre, Auflage 23, Vahlen, München.

Zahn, Sebastian (2015) Kosten Photovoltaik – Das kosten Photovoltaik-Anlagen, online: http://www.energieheld.de/photovoltaik/kosten-pv-anlage.

Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW) (2013, 2012, 2011, 2010, 2009, 2008) Evaluierung der inländischen KfW-Programme zur Förderung Erneuerbarer Energien, Gutachten im Auftrag der KfW Bankengruppe, online: https://www.kfw.de/KfW-Konzern/Service/Download-

Center/Konzernthemen-%28D%29/Research/Evaluationen/Evaluationen-Erneuerbare-Energien/.

ZIEGLER, MICHAEL (2015) Photovoltaik-Preisindex, online: http://www.photovoltaik-guide.de/pv-preisindex.