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Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers

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ABSTRACT

Photovoltaic (PV) system adoption in Germany is mainly driven by a feed-in tariff that guarantees a financial return on investment. To promote adoption in the future absence of this tariff, we explored further motives of homeowners relevant to PV system purchase intention. A sample of 200 homeowners who did not own a PV system participated in an online-survey. Only few homeowners actually planned to adopt a PV system. However, basic willingness to adopt a PV system was high, whereas willingness to pay was low - hinting at a potentially growing market with falling prices. Using path analysis, we show that the subjective norm (i.e. peer behavior and expectations) and the attitude towards PV were strong predictors of purchase intention. Attitude towards PV systems was mainly based on aspirations of social status, autarky, and financial gains, whereas costs, efforts, and risks associated with PV systems were detrimental to attitude. We conclude that to promote further adoption, energy storage systems that increase financial savings and autarky need to be improved and marketed. Furthermore, institutionalized tests of PV systems and labels need to be introduced to reduce risk perceptions among homeowners willing to adopt a PV system.

1. Introduction

Globally, the prevalent method of producing electricity and heat is the burning of fossil fuels [4]. The drawbacks of this *modus operandi* are manifold and lead to growing concerns worldwide [23].

One solution is the use of renewable energies, which reduces pollution, dependence on energy imports, and the waste of fossil fuel resources [26]. It also has the potential to mitigate climate change [4].

Unlike the fossil fuels market, the renewable energy market is open to individuals who want to become electricity producers — especially in the case of residential photovoltaic (PV[1]) systems. Germany, at the end of 2012, had 1.3 million PV systems connected to the grid with a combined capacity of 32 GWp [10,11]. Approximately 90% of these systems were small-scale systems (<30 kWp) purchased by homeowners — accounting for about 45% of total PV capacity [5].

This widespread adoption of PV has been attributed to the German Renewable Energy Act (Erneuerbare-Energien-Gesetz, [12,30]). This Act not only guarantees PV system owners the option to feed the electricity produced by renewable energy systems into the grid, but also a price (feed-in tariff) above market value[2] for every kWh fed in. Location and capacity of new PV installations need to be registered with the federal grid agency (Bundesnetzagentur) to be eligible for the feed-in tariff [12]. The tariff is determined the day the PV system is connected to the grid and fixed for 20 years. Thus, the Renewable Energy Act made PV systems a financially sensible investment, even in the early days when they were expensive and otherwise unprofitable. It kicked off PV system development, and resulted in price reductions not only for PV modules, but also for other components required for a PV system, and for labor cost of installations [27]. Compared to other policy

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[1] Within the scope of this study we focused on PV system adoption due to its versatility. PV produces electricity that can be fed into the grid or partially consumed on site — unlike heat produced by solar thermal or geothermal systems. For many homeowners, PV may be preferable to wind energy for three reasons: 1) it is scalable to the building size and the financial means of the homeowner, 2) it requires little to no maintenance, and 3) it does not change the home's appearance as drastically.

[2] The market value is the price at which electricity is sold at the European Energy Exchange EEX in Leipzig, Germany. The price for baseload power in 2014 was set at 42.12€ per MWh (approx. .04€ per kWh; [16]). Domestic consumers buy electricity from utilities at a price of up to .29€ per kWh [17], which includes various taxes, grid costs, the Renewable Energy Act levy, and other smaller concessions.

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Nomenclature

Alphabetical symbols

N	sample size
n	sub-sample size
p	measure of statistical significance
r	correlation coefficient (Spearman correlation)
R^2	measure of explained variance

Greek symbols

α	Cronbach's α (measure of internal consistency of a scale)
β	standardized regression weight
χ^2	chi-square (measure of model fit)

Abbreviations

df	degrees of freedom
GFI	goodness of fit index (measure of model fit)
GWp	gigawatt peak (measure of maximum power production capacity)
kWh	kilowatt hour
kWp	kilowatt peak (measure of maximum power production capacity)
M	mean value
PV	photovoltaic
RMSEA	root mean square error of approximation (measure of model fit)
SD	standard deviation
SRMR	standardized root mean square residual (measure of model fit)
TPB	Theory of Planned Behavior

instruments, such as quotas or auctions, "feed-in tariffs are by far the most effective policy instruments" ([30], p. 36).

Currently, the feed-in tariff for new installations lies below the consumer price of electricity and further reductions are planned for the coming years [13]. This means that consuming the electricity produced by one's own PV system leads to savings (approx. .29€ per kWh) that are higher than the potential profit earned if the energy was fed into the grid (feed-in tariff: .13€ per kWh for residential PV systems that are smaller than 10 kWp and were connected to the grid in April 2014). Accordingly, the feed-in tariff, which had been credited with attracting investments in PV systems [30], is losing relevance. Thus, the German PV market is becoming more similar to the markets of other countries raising the question: What can stimulate future PV adoption in Germany and elsewhere?

1.1. Adoption of innovation

The adoption of PV systems has been researched in different settings and by using various methods – of which we will present a selection. For an overview of factors determining innovation adoption in general we recommend Rogers' *Diffusion of Innovations* [35].

In California, for example, PV system diffusion in one's street and zip code area predicted further adoption [7], showing that the decision to adopt is subject to peer behavior. Not only does peer behavior offer social learning possibilities, it also sets a norm.

In Hong Kong, the barriers in the adoption of PV systems were high purchase price, long payback periods, inadequate infrastructure, and lack of incentives [45]. Apart from affordability, respondents remarked that grid operators should be obliged to feed the power produced into the grid. Zhang and colleagues (2012) emphasize the role of legislation in incentivizing, but also regulating the market, thus providing security for the investors.

In the Netherlands, a lack in PV adoption was reported even though "grants covered about 90% of the costs of a PV system", showing that financial incentives are not sufficient to promote adoption ([24], p. 1936). Jager [24] stressed the importance of campaigns and forums for discussion to inform potential adopters of the benefits of PV adoption and to reduce the perception of barriers.

In Austria, environmental protection motives, although prevalent among farmers and "reported to be very important in the [PV adoption] decision making process", failed to predict PV system adoption among said farmers ([9], p. 99). To many, the involvement of the trusted *cooperative society of farmers* (Maschinenring) and role models who had already adopted PV systems, offered the security needed to decide upon this large investment.

From a project developer's point of view, investments in large-scale PV systems were mainly dependent on the feed-in tariff and the policy risk, which both differ between European nations [29]. It was found that policy risk translates into monetary costs, as does the duration of administrative processes. Stable political conditions and fast approvals or rejections of PV project proposals can therefore compensate for lower feed-in tariffs.

Outside the realm of PV system adoption, studies on the adoption of solar thermal systems, combined heat and power systems, and even the adoption of energy-saving behavior produced results, which were useful for the present study. Solar thermal systems served as a status symbol for homeowners in Germany [43]. A desire to become energy independent was one motive to take part in a field test of combined heat and power systems [18]. Energy saving behavior could be increased by informing homeowners about average energy consumption in one's neighborhood, but not by informing about the environmental or financial benefits of saving energy [32]. Evidently, pro-environmental behavior and product purchase can be motivated by non-environmental motives.

All in all, the adoption of PV systems is not solely dependent on its environmental benefit, or its price. Policy, infrastructure, incentives, knowledge of the subject matter, and the social context also play a role and need to be considered. In the present study we aimed at integrating these findings and empirically test the claims.

1.2. Predicting purchase behavior

Asking homeowners what it would take for them to purchase a PV system is easy, whereas getting useful answers to this question is difficult, for multiple reasons (see Ref. [42], for an overview): There are many options to improve PV systems as these systems have many attributes. On the one hand, PV systems are designed to save fossil fuels by converting solar radiation into electricity. On the other hand, PV systems are expensive and their production is energy intensive. As none of these attributes is primary, it is difficult to identify what attributes need to be changed to make PV systems more attractive in general (cf. [41]).

Improving one attribute of PV systems might not change homeowners' intentions to purchase the system because objective specifications do not directly translate into subjective perceptions (cf. [14]).

Furthermore, people are often unaware of (or unwilling to admit) what affects their behavior. In a study on energy-saving behavior, participants stated they would save energy for financial and environmental reasons (cf. [32]). However, information about financial or environmental benefits mailed to households did not reduce energy consumption, whereas the mere presentation of