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Original research article

Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market

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A R T I C L E I N F O

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A B S T R A C T

Local factors influencing the rate of diffusion of residential photovoltaic (PV) systems are insufficiently understood. This multiple-case study explored five Swedish municipalities which have had a particularly high PV density in terms of number of installations per capita, compared to other municipalities. The aim was to identify and assess local factors that could explain these relatively high rates of PV diffusion. This was done through a survey sent to PV adopters in the five case municipalities, interviews with local actors and comprehensive Internet search queries. These five cases were also compared to fifty municipalities with low PV diffusion rates, which were studied in less depth. Peer effects (individuals influencing each other to adopt PV) and local organisations promoting PV were identified as important explanatory factors for the high local PV diffusion rates. In particular, electric utilities have successfully taken an active role in supporting PV, purchasing the surplus electricity of PV adopters, selling turnkey PV systems and disseminating information through seminars and their web pages.

1. Introduction

Solar photovoltaics (PV) is a renewable energy technology that is highly suitable for micro-scale electricity generation by private homeowners. This makes PV a radical technology, offering new opportunities while also facing challenges such as uncertainties among potential users regarding durability, performance and compliance with existing regulation and practices [1]. As a response to various subsidy schemes and rapid cost reductions of PV technology, PV sales worldwide have increased dramatically in recent years. In 2013, the global cumulative installed PV capacity reached 140 GW_p, and in that year the added PV capacity accounted for about one third of the total added capacity for renewable electricity production globally [2]. The diffusion of PV systems has hitherto been very unevenly distributed geographically, and until recently, a handful of countries with ambitious subsidy schemes, most notably Germany, accounted for the bulk of the world market. Differences in PV diffusion between countries have, however, been found to follow patterns that cannot be explained by economic profitability alone [3].

The cost reductions of PV modules are a global phenomenon, whereas subsidy schemes and other policy measures and formal rules are largely national. Nevertheless, besides from variation in PV diffusion between countries there have also been significant sub-national variations. Local factors that have been found to drive such differences in per capita PV diffusion include peer-to-peer learning among neighbours [4] and the promotion of PV by local organisations [5,6]. However, the reasons for local variations in PV diffusion have been insufficiently understood. An enhanced understanding of the mechanisms behind these variations could, for example, guide policy makers to design measures to promote PV.

In this paper, it is explored why some Swedish municipalities have had a much stronger diffusion of PV systems than the bulk of Swedish municipalities. The study is designed as a multiple-case study of five municipalities with a particularly high per capita PV density and draws on qualitative data and a questionnaire survey of PV adopters in those municipalities. The aim is to identify and assess factors underlying locally uneven diffusion patterns. While there are several studies on the topic (e.g. [4,6–9]), the results are inconclusive, partly due to a lack of qualitative research on the local level. Moreover, most of the research has been conducted in countries that represent more mature PV markets, and there is little research on local diffusion processes at earlier stages of market development. Recent publications [10,11] have identified a need for more multi-disciplinary research and qualitative methods in energy studies. This paper makes an original contribution to the existing literature on local variations in diffusion and the role of peer effects by conducting research in a very early market

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(Sweden), by combining qualitative and quantitative data and by comparing various factors influencing local variations in PV diffusion.

The paper is structured as follows. In Section 1.1, an account of previous empirical research and related theories are accounted for. In Section 1.2, a brief overview of the Swedish PV market and the institutional setup in which it is embedded is provided. In Section 2, the methodology of the study is accounted for. In Section 3, the results of the case studies are presented, together with a brief account of municipalities with lower levels of PV diffusion for comparison. The last two sections are dedicated to discussion and conclusions.

1.1. *Previous research on local variations in PV diffusion*

There is mounting evidence that local factors play an important role in PV diffusion. Peer effects have been observed in several recent studies, people becoming more prone to adopt a PV system as a result of previous adoptions in their immediate geographical proximity. Bollinger and Gillingham [4] found significant peer effects in California, U.S., at the zip code and street levels. Rode and Weber [12], employing an epidemic diffusion model, found significant and highly localised peer effects in Germany. Graziano and Gillingham [7] and Müller and Rode [13] found significant peer effects in Connecticut, U.S., and the city of Wiesbaden, Germany, respectively, using models based on spatial and temporal distance between installations. Graziano and Atkinson [14] found that spatial peer effects mainly operate within twelve months and one mile of an installation. Differences in research approaches make comparison of these findings somewhat difficult, but the size of the estimated peer effects in terms of increased probability of new adoptions caused by previous adoptions has been estimated to fifteen percentage points per month on the street level and 0.78 percentage points per day on the zip code level [4], while an adoption has been estimated to cause 0.44 new adoptions on the U.S. block group census level [7]. Richter [15] found smaller peer effects for PV in UK zip-code areas. Peer effects in PV diffusion have also been simulated using a network model to assess the likely success of some off-the-shelf policies [16]. Schelly [17] found that early adopters of PV often have a desire to educate others on the benefits of the technology, and that later adopters often found such support of previous adopters helpful. Although many of these studies were also performed on then early PV markets, they were not as early (i.e. small in terms of per capita PV sales and total installed capacity) as the Swedish market during the timeframe of the present study.

Peer effects occurring through positive word of mouth are often important for the successful diffusion of innovations, particularly when the support of a strong brand or strong marketing resources are lacking, which is often the case for small companies marketing radical innovations [18]. As residential PV systems are normally rather visible, there is also a significant *passive* component in the peer effects, occurring as people observe others' PV systems. Rai and Robinson [9] found that PV adopters in Texas, U.S., had been influenced by previous adopters in their neighbourhood both through passive and active peer effects. Brudermann et al. [19] found that word of mouth and attending informative meetings were important factors in the decision making for PV adoption of Austrian farmers.

Other research points to locally active organisations as drivers of spatial variation in PV diffusion. Dewald and Truffer [5] found that local formalised networks of individuals promoting PV could explain much of the geographically uneven distribution of PV market formation in Germany. These networks operated through influencing institutions (e.g. by lobbying for local feed-in tariffs), providing information and implementing demonstration projects. The results of Owen et al. [8] suggest that advisers and installers of low-carbon energy technologies in the U.K. have been highly influential on households' adoption decisions. Noll et al. [6] showed how community-based organisations designed to encourage residential PV adoption in the U.S. managed to leverage the impact of their activities (e.g. information provision and campaigning) through peer effects by engaging local, preferably well-connected, individuals. They also found that existing networks in the community and the presence of local financial institutions providing low interest loans were important factors increasing the rate of PV diffusion. The authors argue that such organisations will have but a marginal impact on the diffusion when the local context is very favourable for PV (i.e. when strong economic incentives drive diffusion) *or* when the context is very unfavourable: it is "in middling context situations" that these organisations have the strongest opportunities of influencing the rate of diffusion. Organisations promoting the diffusion of an innovation can be more generally referred to as *change agencies* [20].

Variation in the provision of local services (including public services) can also explain variation in PV diffusion. For example, variations in permitting procedures have been found to influence costs of PV installations in the U.S [21]. Yet the evidence here is inconclusive: for example, Li and Yi [22]. found that expedited permitting and local solar goals and educational programmes in the U.S. had no significant impact on local variation in PV diffusion.

The current knowledge on local factors influencing the rate of PV adoption is largely from countries that represent fairly mature PV markets, namely the U.S. and, to a lesser extent, Germany. Since local factors are hypothesized to play an important role in the early stage of the diffusion process, other contexts could be studied in order to create more robust and generalizable theories, and to enhance the understanding of how factors on the national level interact with local factors. Moreover, few studies have *compared* the importance of (a) neighbours, (b) local organisations promoting PV and (c) the role of other local factors, such as variations in the local implementation of national policies. The present study aims to address these gaps.

1.2. *PV in Sweden*

Sweden represents an early market, concerning which there is little research yet on local diffusion and peer effects. Before the introduction of an investment subsidy scheme for PV systems in 2005 (through which a fixed percentage of the PV system costs were covered through a rebate), the Swedish market for grid-connected PV systems was almost non-existent, and by the end of 2013 less than 0.1% of Swedish households had adopted a PV system [23]. At such a low level of diffusion, adopters could generally be categorised as innovators and early adopters rather than mainstream consumers [20]. In Sweden, reasons to adopt residential grid-connected PV have mainly related to the adopters embracing a "green" lifestyle, and PV adoption has been "a way to demonstrate an ecological lifestyle to neighbors and friends" [24]. PV has not (with or without subsidies) been financially attractive for most users [25]. The potential for building-sited PV considering Sweden's existing building stock has nevertheless been estimated to be ten to forty terawatt-hours per year [26], which corresponds to about seven to thirty percent of the country's current electricity production. The small but growing Swedish PV market has been almost entirely dependent on the investment subsidy, and few systems have been installed outside of the scheme [27]. As a response to decreasing PV system costs, the scheme's level of remuneration has been stepwise reduced from sixty to thirty-five percent of the system costs during the time period studied in this paper. Today, PV systems are (with subsidies) on the verge of grid parity in Sweden, i.e. the profitability of investing in a PV system is neither particularly high nor very poor from a purely financial point of view.